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American Journal of Diseases of Children

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PHYSIOLOGY OF EXERCISE IN CHILDHOOD

PART 1. A STUDY OF NORMAL CHILDREN OF SCHOOL AGE *

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INTRODUCTION

Muscular exercise is one of the first instincts of the human organism. The stretching out and manipulating of the legs and arms is among the earliest reflexes of the new-born. Because muscular exercise is so constantly a part of daily life and so obvious in its practical application, medical practitioners have come to regard its physiology as an established truth, into the true nature of which search is unnecessary. The subject of muscular exercise should be of more than mere academic interest to the pediatrist. A clearer understanding of the physiology of this subject and the establishment and effective application of physiologic standards will lead to a higher degree of efficiency of our school children and will increase our knowledge of diagnosis in children from a functional point of view. Only on the basis of quantitative scientific investigation of the physical capacity of normal children of all ages and of the effect of muscular activity of all types on the circulatory system, can we ever hope adequately to provide for physical education and successfully to cope with the prevention of those diseases in children which are dependent on muscular deficiency.

When we recall that 30 per cent. of our soldiers were physically defective; when we learn from a survey of 20,000 New York school children that from 20 to 30 per cent. have spinal curvature, that about 10 per cent. have other postural defects, that from 6 to 30 per cent. suffer from malnutrition, that 5 per cent. exhibit other signs of muscular insufficiency; when we understand that in a survey of a public school in Minneapolis, 8 per cent. of the children were found to be asthenic, the analogue of soldiers with "effort syndrome"; when we bear in mind that all of these conditions are preventable and curable by general physical education and properly administered corrective exercises, we must acknowledge the practical importance of a fundamental study of the effect of various types of work and play under all obtaining conditions on the circulatory system of the child.

* Received for Publication Aug. 2, 1922.

* From the Department of Pediatrics, University of Minnesota Medical School.

It may be in place to mention here that the quantitative determination of the mechanical output of the human engine is not as easy as that of a steam engine, for example. In the latter case all factors involved can be measured accurately. The human engine, however, can draw on its reserve power, which varies with different persons, depending largely on a factor ruled by the central nervous system. No method has yet and probably never will be found for its determination. Therefore, the results of a study of the quantity of human muscular output must be relative. This applies also to the data recorded in this paper.

Physiology of Exercise.—In normal children exercise is accompanied by an increase in the pulse rate and the systolic blood pressure. At the very thought of exercise, impulses pass to the inhibitory centers, lessening the vagus tone, and thereby quickening the circulatory reactions.

Immediately after exercise has begun, the curves of the pulse rate and blood pressure ascend abruptly, reaching their apices within about five minutes, and then forming a plateau with slight remissions until the end of exercise.

The contraction of the muscles employed forces the venous blood from the extremities into the great veins, thus causing an overfilling of the right heart; the venous pressure is increased; this, in turn, increases the pulse rate.[1]

Passage of larger amounts of epinephrin into the blood, rise of body temperature, irradiation of impulses from the respiratory center to the vagus nerve, increased H-ion concentration of the blood with its effect on the vagus center, vasoconstriction in the splanchic area and the dilatation of the vessels of the skin and muscles, are other factors influencing the increase of the pulse rate and the blood pressure during exercise.

Work of Previous Authors.—Up to 1920 all investigations of the effect of physical exercise on the circulatory reactions were limited to adults. Though considerable in number they do not permit quantitative conclusions. A comparison of the results is almost impossible, because in many instances neither the type of work (strength or endurance tests) nor the quantity of work were recorded. The outline of the work in which the authors considered at least one of the two factors mentioned above is presented in Table 1. It can be seen that no two investigators employed uniform technic; nor can quantitative standards be established from any of the results obtained because of the small number of subjects studied.

Previous to 1900, the effect of exercise had been studied only on the pulse rate. McCurdy [2] was one of the first in this country to make

1. Bainbridge, F. A.: The Physiology of Muscular Exercise, New York Longmans, Green and Co., 1915, pp. 3 and 187.

2. McCurdy, J. H.: The Effect of Maximum Muscular Effort on Blood Pressure, Am. J. Physiol. **5**:95, 1901; Am. Physical Educat. Rev. **14**:493, 1909.

a systematic study of the effect of lifting heavy weights (strength test) on the pulse as well as on the systolic blood pressure, in a group of trained adults. He found, that the pulse and blood pressure rose rapidly during exercise to fall very quickly to normal after cessation of work, the pulse within sixty seconds, the blood pressure in from two to three minutes. Gruenbaum and Amson,[3] working independently of McCurdy, observed that any form of exercise increased the pulse rate; and that the rise persisted throughout the exercise. The increase varied with the kind, speed and duration of the exercise and was influenced by the training of the subject.

Masing[4] subjected adults of different ages to the same kind of exercise. He concluded:

> Practically all types of work increase the systolic blood pressure in all ages; the rise depends upon the amount and duration of work. The will power greatly influences the rise of pressure in young people. In younger adults the blood pressure remains at about the maximum level throughout the exercise while in older people the initial rise is followed by a fall. Equal quantities of work produce a more rapid and higher rise in the aged than in the young. The increase of blood pressure decreases with repetition of exercise.

Bowen[5] determined the effect of bicycling on the pulse rate and blood pressure during and after exercise. Unfortunately, he did not record the amount of work performed nor the figures obtained. He arrived at the following general conclusions:

> After moderate amounts of work the blood pressure falls rapidly to reach the normal level within a few minutes, contrary to the pulse which after an initial sharp fall remains above normal for a considerable length of time, even for as long as an hour. The maximum rise of peripheral pressure is obtained during the first five to ten minutes of exercise, continuation of exercise causes a slight decrease, and cessation a more pronounced drop to normal or subnormal.

Lowsley,[6] inquired into the effect of moderate and severe exercise on the pulse rate as well as the systolic and diastolic pressures in trained athletes. His findings were: Moderate forms of exercise, as the playing of games for short periods increase the blood pressure not more than ten mms., and the pulse rate from 16 to 36 beats per minute. At the cessation of exercise, the blood pressure and pulse rate fall, the former usually below normal, the latter remaining above normal for a prolonged and variable period. Strenuous exercise for short periods

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3. Gruenbaum, R., and Amson, A.: Einfluss von Bewegung auf die Pulsefrequenz., Wien. med. Presse. **42**:2161, 1901.

4. Masing, E.: Ueber das Verhalten des Blutdrucks des jungen und des bejahrten Menschen bei Muskelarbeit, Deutsch. Arch. f. klin. Med. **74**:253, 1902.

5. Bowen, W. P.: Changes in Heart Rate, Blood Pressure, and Duration of Systole Resulting from Bicycling, Am. Physical Educat. Rev. **8**:8, 232, 1903; Am. J. Physiol. **11**:59, 1904.

6. Lowsley, O.: Effect of Exercise on Pulse and Blood Pressure, J. Physiol. **27**:446, 1915.

TABLE 1.—Work of Previous Authors

Author	Number of Cases	Disease	Type of Exercise	Amount of Work	Normal Pulse	Normal Blood Pressure	During Exercise						After Exercise									Remarks
							Pulse Increase		Systolic Increase		Diastolic Increase		Pulse			Systolic			Diastolic			
													Increase		Reaction Time	Increase		Reaction Time	Increase		Reaction Time	
							Max.	Aver.	Max.	Aver.	Max.	Aver.	Max.	Aver.		Max.	Aver.		Max.	Aver.		
Lowsley	16	.....	Bicycle	?	.....	.....	35-95	51	65 17½′	32	40 30′	22	16-36	..	45′-100′	10	..	48′-60′	11	..	8′-35′	Reaction time 20′+; blood pressure to subnormal, but pulse remained above normal a long time
	6	.....	Mod. exercise, swimming, tennis	½–2 hrs.	.....	.....	..	..	..	..	..	..	..	..	31′ aver.	..	..	31′ aver.	..	..	21′ aver.	
Benedict	16	.....	Fast running	100 yds.	.....	.....	..	..	..	..	..	..	50	45	70′	36	45	70′	..	17	65′	+2
	16	.....	Vigorous exercise, wrestling, running	..... 2-4 mi.	.....	.....	..	..	..	..	..	..	70	39	60′	75	35	124′	40	25	80′	
	8	.....	Fatiguing, running	5-9 mi.	.....	.....	..	..	..	..	..	..	44	..	70′	..	..	70′	..	..	35′	
			Exhausting	10-20 mi.	.....	.....	..	..	..	..	..	..	54	..	213′	39	..	232	39	..	160′	
			Bicycle	1.05 cal. 1.5 cal. 2.0 col. 2.25 cal.	60-64	.....	..	..	..	..	..	..	65 100 108 106	.. ..	150′+ 150′+ 150′+ 150′+							
MacMahon	11	Normal	Dumb-bells 5 lbs., arms	6,000 to 12,000 ft. lbs.	.....	.....	..	..	..	..	..	..	..	41	180″	..	12	180″	..	..	.....	Effort syndrome; blood pressure, 15 second readings for 3 minutes
	50	Effort syndrome	Dumb-bells 5 lbs., arms	.....	.....	.....	..	..	..	..	..	..	..	30+	180″+	..	3-7	180″	..	..	.....	Divides all cases into five groups, from 2,000 to 10,000 foot-pounds
McCurdy	23	Normal	Lifting strength	.....	.....	.....	..	7	70	..	..	..	..	7	60″	..	..	120″				

Bowen	3 30 experiment	Normal, untrained	Bicycle, moderate	400 kg. per minute	.....	.....	Sudden rapid rise, maximum 5′–10′ plateau; drop right after work stops						..... No exact figures												Blood pressure falls very rapidly after work to subnormal or normal, but pulse reaches a plateau and stays above normal for a long time
Cotton-Lewis	..	Controls	Lifted 20 lb. dumb-bells	200 ft. lbs. 400 ft. lbs. 800 ft. lbs. 1,200 ft. lbs.	....	....	.. ..						32 .. 60″ .. 9 50″ 39 .. 110″ .. 18 110″ 56 .. 160″ .. 25 185″ 65 .. 200″ .. 36 260″										
Masing	.....	Normal	Lifting weight with the leg	4 kg. per min. 4 min.	113 (19-21 yrs.) 111 (68-73 yrs.)	.....	19-39	29																	
	9 19-23 yrs.	.....	Lifting weight with one or both legs, Delio	2-5½ kg. in two periods	.....	.....	27-39	33.6	29-49	38.4															
	3 38-50 yrs.	.....	.....	.....	.....	.....	31-43	37	34-59	49															
	4 58-81 yrs.	.....	.....	.....	.....	.....	17.5-40.5	26.3	24-66.5	51.5															
Moritz	6 2 exper. each, 21-32 yrs.	Normal	Delio (see Masing) leg or finger	567 kg. 25.2 420 6.4 264 16 216 14.4 162 21.6	84 84 64 68 68 64 72 68 56 56	140 145 133 127 142 138 155 158 128 120	16 .. 45 .. .. .. 16 .. 30 .. .. .. 49 .. 7 .. .. .. 22 .. 23 .. .. .. 22 .. 30 .. .. .. 8 .. 15 .. .. .. 18 .. 16 .. .. .. 22 .. 25 .. .. .. 24 .. 16 .. .. 25						22 .. 35′ 22 .. 35′ .. .. —4 .. 7′ .. .. 17′ 8 .. 12′+ 7 .. 9′+ .. .. 7′+ 8 .. 7′ 4* .. 11′ 10* .. 11′ 4 .. 7′+ 5 .. 8′ 4 .. 14′+ 3 .. 14′ 10 .. 11′ 4 .. 11′ 8 .. 12′ 0 .. 1′ . .. 13′ 5 .. 14′?										The quantity of fatigue, not the quantity of work determines the heights of the blood pressure. The blood pressure rises in proportion to the energy and will power to continue the exercise in spite of tiredness. Blood pressure and pulse taken at one minute intervals during and after exercise
		Myodegeneration	One leg Running	88 kg., 5 min. 66.8 kg., 19 min. 2 mi. 1 mi.	....	....	.. ..						76 .. 107 96 .. 15 74 .. 60										

* Two minutes after exercise.

(100 yard dashes) causes a rise of about 45 mm. of the systolic blood pressure and of 45 beats per minute in the pulse rate. The reaction time of the pulse (return to normal) occurs within sixty minutes; wrestling delays still more the reaction time of both pulse and blood pressure. After exhaustive exercise (runs of ten to twenty miles) the circulatory reactions remain abnormal for several hours.

Cotton and Lewis [7] studied the effect of exercise with twenty pound dumbbells in soldiers. They reported that the blood pressure showed an abrupt rise at the beginning of exercise, a decided drop at its cessation and a return to normal within four minutes. The pulse rate was found to increase on the slightest effort, the maximum rise appearing at the end of work, to decline abruptly at cessation of work.

Cotton and Lewis stated that, in general, the amount of work determined the rise of systolic blood pressure, and the rate of work the rise of the pulse rate.

In summing up the work of these authors, the differences in their conclusions have to be ascribed to the differences in their technic and the lack of normal standards.

They all agree that (1) all forms of exercise increase the pulse rate and blood pressure; (2) the rise and the reaction time are proportionate to the quantity and the speed of exercise and (3) strength tests cause a sharper and higher increase of the pulse rate and blood pressure during exercise, the latter returning more quickly to normal in strength tests than in any other form of exercise.

The Effect of Posture on the Pulse Rate and Blood Pressure.—The literature on blood pressure and pulse in normal children is insufficient and inconstant. Therefore, we considered a careful study of this subject necessary. About 600 determinations were carried out on 100 children, between the ages of 6 and 15 years. The systolic and diastolic pressures, as well as the pulse rate, were taken in the standing, sitting and reclining postures. The determinations were made with the Baumanometer sphygmanometer by the auscultatory method. The cuff used was 9 cm. wide, and the right arm was always employed. Careful explanation as to the technic was given to every child so as to exclude the possibility of excitement. It proved advisable to begin with the standing posture. The first blood pressure reading was always discarded. At least three readings were taken at each sitting. In some instances, the reading was continued for as long as fifteen minutes, until constant figures were established. The same procedure was observed in the sitting position and finally in the lying. For ascertaining the diastolic pressure it is essential, especially in children under 10 years of

7. Cotton, T. F., Rapport, D. L., and Lewis, T.: After Effects of Exercise on Pulse Rate and Systolic Blood Pressure in Cases of "Irritable Heart," Heart **6**:269, 1917.

age, to keep the arm at right angle to the body, so as to avoid constriction, otherwise pulse pressures of ten mm. and below may be obtained. The pulse rate was counted simultaneously by auscultation.

The figures in Tables 2 to 12 represent the averages of three or more determinations carried out on different days, though under con-

TABLE 2.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGE 6 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
B. D.	6	53.5	47.75	96	67	29	85	54	31	86	56	30	81	85	83
E. B.	6	47.5	44.5	97	66	31	84	55	29	90	62	28	79	91	90
M. E.	6	44.5	46	99	71	28	86	61	25	85	60	25	91	93	90
A. T.	6	56	48	102	76	26	94	70	24	97	75	22	110	121	125
4 cases	6	50.4	46.5	99	70	29	88	60	28	90	62	28	90	98	100

TABLE 3.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGE 7 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
M. B.	7	53.5	49.75	105	73	32	88	62	26	90	64	26	73	79	78
E. B.	7	51	46.75	97	77	20	91	66	25	89	65	24	96	103	103
C. K.	7	58	47.5	104	77	27	99	74	25	97	72	25	84	97	95
L. D.	7	54.75	48	105	76	29	95	65	30	96	66	30	92	96	104
C. J.	7	50.75	48.75	92	62	30	77	58	29	77	50	27	87	96	102
J. M.	7	49.5	46.5	116	86	30	110	80	30	105	77	28	82	88	78
H. R.	7	47.25	46.75	93	63	30	82	55	27	79	51	28	88	93	95
T. S.	7	58	47.5	100	70	30	92	62	30	96	67	29	86	87	93
H. S.	7	45	46.75	102	85	17	88	70	18	87	70	17	98	105	102
U. W.	7	61.5	51	111	85	26	104	79	25	102	76	26	83	98	101
10 cases	7	52.8	47.9	102	75	27	94	67	27	92	66	26	87	94	95

TABLE 4.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGE 8 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
H. B.	8	79.5	52.75	106	75	31	95	66	29	96	68	28	83	100	98
J. C.	8	57.5	48	107	78	29	95	65	30	95	66	29	86	101	101
O. F.	8	55	49	103	80	23	93	71	22	95	73	22	82	91	94
J. J.	8	51.5	51.5	99	76	23	91	67	24	91	68	23	69	75	73
M. G.	8	71.75	53.5	106	77	29	94	65	29	98	68	30	82	92	96
W. P.	8	59	49	103	79	24	94	71	23	91	69	22	81	89	88
G. S.	8	60.25	48	107	80	27	93	67	26	92	69	23	81	86	93
M. S.	8	60.25	49.75	95	71	24	86	63	23	85	62	23	78	96	103
J. P.	8	76.75	52.5	109	83	26	99	76	23	100	76	24	70	72	70
J. V.	8	55.75	48.5	103	78	25	90	64	26	93	64	27	79	84	78
10 cases	8	62.75	50.25	104	79	25	93	68	25	94	68	26	79	88	89

ditions as alike as possible. The pulse rates found confirm the work of previous authors, the pulse rate being higher in the sitting than in the lying position and higher in the standing than in the sitting position. There is no constant increase with age in any of the three postures. There exists, however, a definite relation between the rate in the standing and the sitting posture, on the one hand, and the lying posture on the

other. The average ratio $\frac{\text{Rate standing}}{\text{Rate sitting}} = 1.06$ (with a maximum of 1.16 and a minimum of 1.01). $\frac{\text{The rate standing}}{\text{Rate lying}} = 1.15$ (with a maximum of 1.328 and a minimum of 1.09). In the lying posture the average pulse rate for all ages equals 79, the probable error ± 3.069, the coefficient of

TABLE 5.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGE 9 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
J. B.	9	79	56	117	89	28	106	79	27	106	76	30	78	104	107
M. B.	9	65.5	53	111	87	24	100	75	25	198	74	24	75	90	93
I. G.	9	58.5	51.5	100	78	22	83	63	20	91	70	21	73	78	84
H. G.	9	61.5	51.5	106	84	22	93	69	24	95	73	22	96	103	104
H. G.	9	59	50.25	101	77	24	96	74	22	92	68	24	76	78	77
C. H.	9	67	53.25	98	77	21	89	68	21	87	66	21	82	90	98
M. L.	9	57	51	92	65	27	86	63	23	85	64	21	84	91	93
R. O.	9	68.75	53.5	104	76	28	99	73	26	98	70	28	92	103	108
H. W.	9	79.50	55.75	110	80	26	98	75	23	95	75	20	81	81	87
H. W.	9	62.5	49.5	99	67	22	94	74	20	90	70	20	67	77	79
10 cases	9	65.8	52.25	104	78	26	94	71	23	94	71	23	70	80	93

TABLE 6.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGE 10 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
G. C.	10	67	52.75	100	82	18	89	67	22	94	75	19	87	100	114
H. A.	10	67	53.25	121	87	34	112	81	31	112	80	32	82	88	92
F. C.	10	71	55	105	73	32	95	66	29	97	70	27	70	74	90
A. H.	10	60	50.25	111	86	25	100	75	25	92	67	25	67	79	87
J. H.	10	104.5	56.25	114	85	29	102	75	27	101	72	29	73	79	82
C. J.	10	91	53.75	106	81	25	90	67	23	89	63	26	75	87	93
H. S.	10	74	55.5	102	78	24	90	69	21	92	70	22	82	93	92
B. G.	10	65.5	52.5	95	73	22	82	60	22	87	66	21	86	89	93
A. F.	10	64.5	52.25	106	83	23	88	64	24	92	69	23	76	82	76
9 cases	10	74	53.5	107	81	26	94	69	25	95	70	25	78	86	91

TABLE 7.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGE 11 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
S. B.	11	74.5	55	103	78	25	95	67	28	99	72	27	99	79	89
G. D.	11	70	52.75	114	87	27	100	75	25	96	70	25	64	70	76
A. G.	11	79.5	55	115	86	29	102	73	29	104	76	28	85	88	98
P. H.	11	89.5	57.5	111	82	29	100	73	27	97	70	27	74	81	75
P. M.	11	82	54.75	111	80	31	100	73	27	103	76	27	59	71	89
E. R.	11	96.5	60.5	105	78	27	99	63	26	87	62	25	76	79	82
H. R.	11	73.75	52.75	100	75	25	87	64	23	88	64	24	79	87	82
L. S.	11	53	49	107	82	25	94	71	23	94	70	24	72	78	76
E. W.	11	60	52.5	104	78	26	94	69	25	94	69	25	76	81	92
V. B.	11	74	55.25	100	71	29	92	62	30	91	61	30	74	90	92
10 cases	11	75	54.5	107	80	27	96	69	26	95	69	26	76	80	85

variability 5.75; in the sitting posture the average pulse rate is 86, the probable error ± 3.97 and the coefficient of variability is 6.83; in the standing position 91 was found to be the average for the pulse rate, ± 3.02 for the probable error and 4.908 for the coefficient of variability.

TABLE 8.—Effect of Posture on Blood Pressure and Pulse—Age 12 Years

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
J. B.	12	88.5	58	105	83	22	91	67	24	86	63	23	66	70	73
R. B.	12	78	55.75	107	81	26	96	70	26	95	71	24	72	92	93
B. B.	12	62.5	52.75	120	95	25	103	76	27	103	76	27	86	88	88
J. D.	12	68	52.5	118	92	26	104	80	24	102	75	25	76	89	91
T. B.	12	83	55	110	86	24	98	72	26	102	77	25	70	80	83
D. Z.	12	100	58.25	112	82	30	109	77	32	108	78	30	77	87	88
A. J.	12	74	57.25	116	91	25	107	86	21	101	78	23	64	66	68
A. G.	12	86.5	60	116	82	34	103	72	31	103	72	31	66	74	75
C. P.	12	91.5	57.5	110	85	25	102	74	28	94	67	27	90	98	98
M. R.	12	74	56	103	73	30	89	60	29	92	63	29	70	94	100
M. S.	12	81.5	54	104	77	27	96	72	24	99	71	28	73	78	79
J. T.	12	76	55.5	102	76	26	99	74	25	100	72	28	82	88	96
12 cases	12	80.3	56	110	84	27	100	73	26	99	72	27	74	84	86

TABLE 9.—Effect of Posture on Blood Pressure and Pulse—Age 13 Years

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
P. C.	13	92	60	108	73	30	96	67	29	102	72	30	82	98	101
M. B.	13	95	60	113	84	29	102	74	28	95	66	29	73	89	93
B. C.	13	88	60	101	78	23	95	74	21	96	76	20	73	85	81
D. H.	13	90	59	113	84	29	109	81	28	102	78	24	86	94	103
C. J.	13	95	59	105	74	31	87	65	22	88	68	20	68	86	94
W. M.	13	122	63	118	83	35	109	75	34	108	75	33	80	94	93
E. L.	13	75	56	103	65	38	93	53	40	97	55	42	74	78	80
B. M.	13	80	56	107	67	30	95	66	29	96	66	30	81	86	91
C. P.	13	78.5	55	106	81	25	101	72	29	101	74	25	83	84	96
A. P.	13	112.5	62	124	93	31	106	75	31	104	73	31	88	92	91
C. S.	13	90	60.5	100	72	28	99	70	29	100	73	27	60	73	76
L. S.	13	83	60.75	92	58	34	81	57	24	81	53	28	74	80	90
M. S.	13	85	59.75	97	70	27	89	65	24	93	68	25	75	83	85
L. W.	13	124	66	117	79	32	99	72	27	110	79	31	77	82	87
M. W.	13	100	67	119	85	37	113	80	32	112	80	32	78	76	76
D. Z.	13	99	61	111	88	23	99	75	23	99	76	24	86	88	92
16 cases	13	94	59	108	76	30	98	68	28	99	68	28	78	85	89

TABLE 10.—Effect of Posture on Blood Pressure and Pulse—Age 14 Years

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
H. B.	14	118	63.2	114	83	31	100	70	30	92	63	29	90	98	101
J. B.	14	109	63	116	86	30	110	76	34	112	79	33	77	85	93
J. C.	14	93	60	105	76	29	108	84	24	100	76	24	60	74	82
A. F.	14	85	59	106	80	26	95	69	26	94	70	24	69	89	95
H. F.	14	85	59	111	83	28	97	70	27	104	78	26	70	80	78
R. G.	14	122	63	121	97	24	101	73	28	102	73	29	75	72	76
H. H.	14	75	56	105	84	19	96	74	22	99	78	21	79	91	94
C. H.	14	93	59	116	88	28	109	77	32	103	76	27	79	85	89
A. K.	14	74	51	115	87	28	106	81	25	107	86	21	72	82	82
M. K.	14	96	58	112	83	29	104	75	29	99	69	30	83	91	92
H. P.	14	93	63	109	81	28	93	64	29	92	65	27	97	102	105
E. R.	14	97	59	110	86	24	98	75	23	96	61	25	73	85	90
H. R.	14	99	62	124	95	29	112	86	26	113	87	26	72	78	84
M. S.	14	120	65	139	93	46	118	80	38	117	77	40	80	85	86
W. T.	14	76	58	109	85	24	100	74	26	97	70	27	73	81	80
F. L.	14	109	61	122	86	36	112	78	34	118	81	37	84	91	94
16 cases	14	96	59	114	85	28	104	76	28	102	74	28	78	79	88

Analyzing the blood pressure readings in Table 12 one notices, on the whole, a slight increase of the systolic pressure from year to year in all three postures. This is not true of the diastolic pressure. The pulse pressures, however, are fairly constant for all ages and all postures. The averages of the systolic, diastolic and pulse pressures in the three positions, their probable error and coefficient of variability are recorded in detail in Table 13.

TABLE 11.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGE 15 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
Subject	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
E. B.	15	104	62.5	115	86	30	108	76	32	102	67	35	87	95	108
A. B.	15	125	68.5	116	83	33	86	55	31	104	58	46	..	84	
A. F.	15	116	63	116	75	41	100	67	33	96	64	32	72	82	91
L. P.	15	110	62.5	127	96	31	107	74	33	108	76	32	86	100	101
M. R.	15	102	60.5	108	79	29	102	70	32	101	72	29	78	80	88
W. S.	15	107	64	115	85	30	101	70	31	100	70	30	81	94	93
6 cases	15	110.7	63.5	116	84	32	101	69	32	102	68	34	81	89	96

TABLE 12.—EFFECT OF POSTURE ON BLOOD PRESSURE AND PULSE—AGES 15-6 YEARS

				Blood Pressure									Pulse		
				Lying			Sitting			Standing					
of Cases	Age in Yrs.	Weight in Lbs.	Height in In.	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Lying	Sitting	Standing
6	15	110.7	63.5	116	84	32	101	69	32	102	68	34	81	89	96
16	14	96	59	114	85	28	104	76	28	102	74	28	78	79	88
16	13	94	59	108	76	30	96	68	28	99	68	28	78	85	89
12	12	80.3	56	110	84	27	100	73	26	99	72	27	74	84	86
10	11	75	54.5	107	80	27	96	69	26	95	69	26	76	80	85
9	10	74	53.5	107	81	26	94	69	25	95	70	25	78	86	91
10	9	65.8	52.25	104	78	26	94	71	23	94	71	23	70	80	93
10	8	62.75	50.25	104	79	25	93	68	25	94	68	26	79	88	89
10	7	52.8	47.9	102	75	27	94	67	27	92	66	26	87	94	95
4	6	50.4	46.5	99	70	29	88	60	29	90	62	28	90	98	100

TABLE 13.—STATISTICAL DATA FOR BLOOD PRESSURE IN VARIOUS POSTURES

	Standing			Lying			Sitting		
	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure	Systolic	Diastolic	Pulse Pressure
Average.....	96	68	27	108	80	28	96	69	27
Probable error.....	2.629	2.196	1.847	3.406	3.047	1.366	2.971	2.664	1.61
Coefficient variability...	4.061	4.787	10.14	4.676	5.645	7.231	4.581	5.724	8.84

The probable error for the systolic and diastolic pressures of all ages ranges from ± 1.5 to ± 3.4, the coefficient of variability of the systolic and diastolic blood pressures lies between 4.0 and 5.6 for the three postures. The error for the pulse pressure is about ± 2 and the coefficient of variability from 7 to 10.

Comparing the systolic and diastolic blood pressures in the three postures, one finds that the blood pressure in the lying position is invari-

ably higher than that in the sitting position, and that in the sitting position it is practically always higher than that in the standing position. This differs with the conclusions of some investigators on the blood pressure in normal adults. It should be emphasized at this point that the technic remained the same throughout all readings and that the blood pressure in the supine position was taken after those in the other positions. In some instances, the order was changed with no change in the results. The average ratio of $\frac{\text{Blood pressure lying}}{\text{Blood pressure sitting}} = 1.14$ (maximum $= 1.15$, minimum $= 1.085$) and the average ratio of $\frac{\text{Blood pressure lying}}{\text{Blood pressure standing}} = 1.11$ (maximum equals 1.127, minimum equals 1.09). As stated before, the average ratio of the pulse rate in standing to sitting was 1.06 and that in standing to lying 1.15. The ratio for the systolic blood pressures in the various positions, is practically inversely proportional to the ratio of the pulse rates in the same position. In other words, the $\frac{\text{Blood pressure lying}}{\text{Blood pressure standing}}$ about $= \frac{\text{Pulse standing}}{\text{Pulse lying}}$

TECHNIC AND PLAN OF WORK

Ergometer.—It has been mentioned above that the lack of uniformity in technic on the part of previous authors made impossible deductions for standards on the circulatory reactions after exercise. To accomplish this the authors decided to use the ergometer, in a modified form (Figs. 1 and 2). A bicycle is made stationary by fastening it to a wooden platform. The electric brake (used by other experimentors) is supplanted by a mechanical brake (Prony Brake)[8] (*b*) which consists of wooden strips attached to a piece of leather belting. The resistance to work is standardized by means of a screw (*c*) and measured on a scale (*d*) of four pound capacity, with sixteen divisions for each pound. The pointer (*e*) on the scale is practically prevented from vibrating by a damper (*f*) on the beam (*g*), the length of which is $\frac{63.025 \text{ inches}}{4 \times 12}$ (one-fourth of the standard size). The wheel (*h*) of the pulley carries a cyclometer (*i*) which records the number of revolutions for a given period. Daily lubrication of the brake allows for smooth riding. Two bicycles were built, one for children 58 inches in height and over, the other for smaller children. The experiments were carried out in one of the Minneapolis Public Schools. All the subjects were within the normal limits of height, weight and general physical development. Complete physical examination was made in

8. A foot-pound equals the work done in lifting a pound one foot high against the force of gravity. There is about 1% error on account of friction of the bicycle chain and in the reading of the scale. The formula used depends upon the lifting of a load around a circle of which the beam is the radius. We want to express our sincere thanks to T. B. Rowley and B. J. Robertson, Prof. and Associate Prof. of Mechanical Engineering, respectively, for their help in the building of the Ergometer.

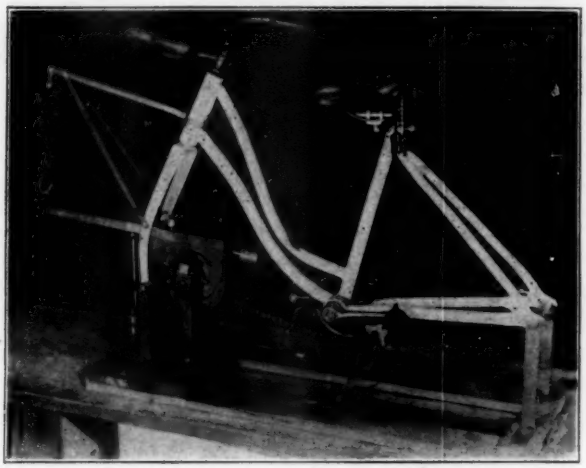

Fig. 1.—The ergometer is fastened to a bicycle frame.

Fig. 2.—This illustration shows in detail how the ergometer is attached to the front of the bicycle frame.

every instance so as to exclude those afflicted with rhinitis, tonsilitis, bronchitis and other infections occurring frequently during the winter. With very few exceptions the children were zealous in their efforts to prove that "they were strong" and that "their hearts were good." The competitive spirit so splendidly developed in the American child resulted in delightful cooperation.

First a questionnaire (Fig. 3) was answered. Next the pulse and blood pressures (systolic as well as diastolic) were determined in the three postures. Before the experiment on the ergometer, the child was made familiar with the technic by explanation and by a demonstration on another child.

On the next day, the blood pressure was again taken standing and sitting on the bicycle as on the previous day. The blood pressure

Name	School	Grade	Age	Sex	Ftlty.	Col.	Type	Temp.	Studious	Athlet.	Wt.	Ht.	Stat.	Devel.	Musclotone

Legs	Chest	Last Sick	Hrs. Sleep	Southbridge Ther	Diagnosis	Roentgen Ray	Electrocardiograph

Experiment No.

BEFORE EXERCISE	Pulse	Bl.Pr.	V.C.
Lying			
Sitting			
Standing			

Fig. 3.—Data sought by means of the questionnaire.

Name: Room:

Experiment No. Date Time n.p. n.Bl.Pr.

Min.	Counter Rev.	Remarks	Rev.	Footpds.	Pulse	Sec.*	Bl.Pr.	Remarks

*Separate horizontal lines are ruled for seconds 5 & upward.

Fig. 4.—Headings on blank used to record the observations made on each child.

readings in the sitting posture were repeated until uniform. The pulse rate was ascertained simultaneously with the stethoscope.

By this time the child had become accustomed to the apparatus, the blood pressure cuff and the workers. The feet of the subject were fastened to the pedal by means of two straps in crosswise adjustment. The blood pressure and pulse rate were again determined. This procedure was absolutely necessary for obtaining correct readings, the irregularities and inconstancies being thus eliminated. If, in spite of all these precautions, the first reading of the blood pressure in the sitting position was 4 mm. above the following readings, it was discarded. Then the riding capacity of the child was tested. The child was instructed to go as fast and as long as possible and not to stop until so advised. The number of revolutions and the duration of the experiment were noted on a blank as shown in Figure 4. It

took from five to seven seconds to adjust the screw on the brake. All the signs and symptoms observed during exercise were also recorded on the chart. Severe perspiration, as well as extreme dyspnea, were taken as the index of maximum physical effort. Thirty seconds before the end of the experiment the child was reminded to lay its arm on the wooden support at the word "stop." The blood pressure cuff was kept partly inflated for the last three seconds so as to avoid any delay in determining the first blood pressure reading after exercise. Thus, in the majority of experiments the first reading was taken within from three to five minutes after exercise, and only in rare instances as late as after ten seconds. The readings of the blood pressure were repeated at periods of ten seconds for the first minute and at periods of thirty seconds thereafter until the blood pressure had returned within 2 mm. of the preexercise level. In the pulse five beats per minute were allowed as a limit of normal variation. It was found in a hundred determinations that the average difference between the highest and lowest blood pressure readings was 2 mm., and the average variation in pulse rate was five beats.

The technic of the dumbbell and staircase exercise will be described in detail later.

Comparison of the Effect of Different Types of Exercise on the Circulatory Reactions.—It has been determined by other investigators that short periods of work, especially work involving speed rather than strength, always causes an increase in the pulse rate, the latter returning to normal within a few minutes, depending on the speed and the kind of work. The dumbbells are the most popular apparatus with which the clinical physiology of muscular exercise has been studied in the last few years. Wilson,[9] experimenting with dumbbells at the rate of two seconds for each swing, found that in 63 per cent. of her subjects who had reached the point of fatigue (+++ dyspnea), the rise in pulse rate was proportional to the increase in work. In 60 per cent. the maximum rate accompanied the maximum amount of work. In 52 per cent. of the experiments the reaction time to normal was 120 seconds, and in 28 per cent. the pulse became subnormal at the end of two minutes. In 13 per cent. the pulse remained above normal at the end of two minutes. In the majority of her cases the pulse returned to normal within one hundred and twenty seconds whether the subjects were only slightly fatigued or markedly exhausted. She did not state whether the pulse rate in

9. Wilson, May G.: The Circulatory Reactions to Graduated Exercise in Normal Children, Am. J. Dis. Child. **20**:188, 1920. Exercise Tolerance of Children with Heart Disease as Determined by Standardized Test Exercises, J. A. M. A. **76**:1629 (June 11) 1921.

the mild exercises in which no dyspnea was produced returned to normal earlier than in the more severe exercises.

Wilson also claims that the type of curve showing a delayed rise of the blood pressure and a prolonged fall "was present in 88 per cent. of the experiments and in 85 per cent. it was accompanied by clinical symptoms of marked dyspnea and fatigue. The rise of blood pressure varied from 2 to 55 mm. The maximum blood pressure reading was 160. The rise varied directly with the increased quantity of exercise, and in 92 per cent. of the experiments the rise was proportional to the amount of dyspnea and fatigue."

In view of Wilson's claim it was thought expedient to include a similar study in this treatise.

Dumbbell Arm Exercise.—Thirteen experiments were carried out, the subjects lifting two four-pound dumbbells from the shoulders to full arm length. The child swung to the limit of his capacity. The blood pressure and pulse were taken before and immediately after exercise. The circulatory reactions are recorded in Table 14. It can be seen that the average rise of the blood pressure amounted to 15.2 mm. in the smaller children, who averaged forty swings, and 32.6 mm. in the older children, who averaged ninety swings. The average reaction time was 221 seconds for all subjects. The maximum rise occurred between 5 and 30 seconds in approximately 70 per cent. of the cases. In none of the experiments was a delayed rise present, although the subjects showed subjective signs of exhaustion. The pulse rate returned to normal within two minutes in practically all the cases (Table 15 A). The increase in the pulse rate averaged 42.6 beats.

Full Length Lift.—In thirty-one experiments two 4-pound dumbbells were lifted from the floor the length of the arm above the head, one full swing lasting two seconds. Wilson's technic was followed. It was found that the pulse rate and the blood pressure increased in proportion to the number of swings. The average rise in the pulse rate was 34.9 after ten swings, 58 after thirty swings and 72.6 beats after sixty swings (Table 15 B.). The blood pressure rose on an average of 23.6 mm. after ten swings, 28.9 mm. after thirty swings and 32.7 mm. after sixty swings. The reaction time of the blood pressure also increased with an increase in the number of swings, the reaction time being 154 seconds after ten swings, 213 seconds after thirty swings and 281 seconds after sixty swings. The maximum reading of the blood pressure obtained between 5 and 30 seconds in 100 per cent. of the experiments after ten swings, in 37 per cent. after thirty swings and in 70 per cent. after sixty swings. Wilson claims that there is an increase in the time of maximum reading with

TABLE 14.—Effect of Different Types of Exercise on the Circulatory Reactions

Type of Exercise and Subject	Age in Years	Weight in Pounds	Height in Inches	Number of Swings	Foot-Pounds of Work	Pulse					Systolic Blood Pressure						
						Before Exercise	After Exercise				Before Exercise	After Exercise					
							Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Sec.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.
Dumbbells, Body Exercise																	
H. G.	9	61½	52¼	10	412	90	120	5	30	90	101	113	5	120	20	19	180
				30	1,236	100	170	5	70	120	98	115	10	123	35	25	180
				50	2,060	90	160	10	70	270+	98	117	10	129	30	31	300
I. P.	9	76¾	52½	10	422	86	110	10	24	60	103	127	10	132	20	29	180
				30	1,266	90	160	5	60	60	107	122	10	132	40	25	150
				60	2,532	90	170	10	80	60	107	130	10	147	50	40	300
H. S.	10	74	55¼	10	435	90	130	10	40	40	96	109	10	112	30	16	150
				30	1,305	90	150	5	60	60	91	109	20	115	30	24	150
				60	2,610	90	170	5	80	150+	90	118	10	122	20	32	180+
A. H.	11	60¼	50¼	10	402	76	120	5	44	150	96	117	10	120	20	24	120
				30	1,206	78	132	5	54	90	99	124	10	125	10	26	180
				60	2,402	76	144	5	68	180+	98	133	10	135	10	37	270+
S. B.	11	75	55½	10	437	84	120	10	36	40	95	112	10	116	20	21	90
				30	1,310	74	120	5	46	60	94	116	10	116	10	20	270
				53	2,316	78	120	5	42	50	98	115	10	121	40	23	150
A. G.	11	79¼	54¾	10	430	90	100	10	10	50	108	130	10	132	10	24	180
				30	1,290	90	140	10	50	60	110	120	10	130	50	20	390
				10	430	90	120	10	30	90	111	116	10	126	20	15	150
				30	1,290	100	140	5	40	50	111	128	10	136	20	25	300
				60	2,580	90	170	10	80	210	115	140	10	150	45	35	360
B. Br.	12	62½	52¾	10	418	72	115	5	43	50	99	127	5	133	20	34	150
				30	1,256	78	132	5	54	60	111	149	5	149	5	38	240
				60	2,512	78	144	5	66	150	101	138	5	145	30	44	390
J. D.	12	68	52½	10	416	84	120	10	36	20	111	135	5	148	20	39	150
				30	1,248	84	144	5	60	40	110	138	5	147	20	37	180
				60	2,496	84	144	5	60	40	113	145	5	148	20	35	210
R. B.	12	78	55¾	10	437	90	144	5	54	120	111	119	10	130	30	19	180
				30	1,310	96	168	5	72	90	105	129	5	147	40	42	270
				60	2,621	84	180	5	96	150	102	130	10	141	30	39	330
M. H.	15	75	56	10	440	90	120	5	30	90?	107	128	5	129	5	22	120
				10	440	90	132	5	42	40	96	111	10	117	20	21	150
				30	1,320	84	132	10	48	60	100	128	10	136	30	36	270
				60	2,640	84	168	5	84	60	99	138	5	150	30	51	390
Dumbbells, Arm Exercise																	
I. C.	8	57½	48	40	360	90	132	10	42	60	98	108	10	102	20	14	150
				40	360	90	132	10	42	60	102	118	10	118	20	16	210
M. S.	8	60½	49¾	40	360	90	120	10	30	40	103	102	20	103	20	13	180
				30	324	90	120	30	30	60	83	101	30	101	30	18	300

G. S.	8	60¼	48	40	360	90	120	10	30	50	92	104	20	108	40	16	180
				50	450	84	132	10	51	60	91	105	20	105	20	14	180
M. K.	14	96	48	64	787	96	120	10	24	60	104	129	10	129	10	25	150
				75	922	84	108	10	24	40	99	111	20	116	40	17	180
				81	996	84	96	10	12	45	104	122	10	127	20	23	150
				86	1,273	78	132	10	54	150	106	121	10	128	30	22	180
F. L.	14	109½	61	90	1,305	78	156	20	78	40	114	137	20	149	30	35	270
				100	1,450	84	144	10	60	40	106	152	10	159	40	53	
				110	1,595	84	132	10	48	40	117	157	5	159	5	42	240
				125	1,813	84	156	5	72	90	114	155	10	158	30	44	300
Staircase Test																	
I. C.	8	57½	48		1,311	100	216	20	116	180	101	122	30	125	40	24	420
					1,311	100	168	30	68	180	101	124	30	127	40	26	360
G. S.	8	60¼	48		1,581	96	180	10	84	360	98	128	30	128	30	30	360
					1,581	96	168	30	72	90	98	127	30	128	30	30	420
M. S.	8	60¼	49¾		1,581	96	156	20	96	90	96	105	20	123	40	27	330
				Three	1,581	96	156	20	60	60	96	104	10	116	30	20	270
				flights	1,581	98	168	30	70	120	91	112	30	112	30	21	330
				of	1,581	96	180	10	84	150	91	93	10	109	50	17	270
M. K.	14	96	58	Stairs	2,520	83	168	30	85	240	106	146	30	149	50	43	
					2,520	84	156	30	72	450+	106	139	30	149	50	43	390
F. L.	14	109½	61		2,890	84	180	10	96	60	117	144	10	148	20	31	360
					2,890	96	168	10	72	120	119	150	20	162	40	43	
					2,890	84	144	10	60	150	117	144	10	158	25	40	
					2,890	84	156	10	72	150	117	154	10	158	30	41	480
					2,894	84	180	10	96	90	117	167	10	167?	10	50?	390
Ergometer Readings for 1, 2, 3 and 4 Min.				**No. of Min.**													
I. C.	14	93	60¼	1	5,838	84	156	5	72	480+	109	146	5	163	30	54	360
					5,368	90	168	5	78	210	112	141	5	155	20	43	270
					4,508	84	168	5	84	270	109	146	20	149	50	40	240
					5,281	84	168	5	84	180	108	147	5	149	5	41	270
				2	9,941	84	180	5	96	540	116	147	5	163	40	47	360
				3	12,465	84	180	5	96	600+	102	156	5	171	50	67	660+
H. B.	14	118	63	1	6,268	108	168	5	60	180	107	157	5	157	5	57	390
					6,199	100	168	5	68	360	105	151	5	163	50	58	360
					9,748	100	...	..	..	...	...	...	..	164	10	52	390
				2	10,788	102	168	5	66	360	106	157	5	161	40	55	390
					11,624	100	168	5	68	300	103	167	5	173	50	70	510
D. G.	13	100	58¼	1	4,041	108	144	20	36	50	120	124	5	126	5	6	50
					3,798	120	160	5	40	150	110	125	5	134	40	24	360
					4,370	105	150	5	45	180	110	125	5	134	10	24	300
				2	8,165	108	156	5	48	600+	120	154	10	154	10	34	270
					8,248	105	150	5	45	180	110	120	5	132	20	22	300
				3	11,875	108	144	36	36	360	112	133	5	143	20	31	300
					12,044	105	170	5	65	450+	110	125	5	142	5	27	240
					12,040	108	168	5	60	360+	115	140	5	142	5	23	390
				4	14,886	108	168	5	60	360+	115	140	5	142	5	27	240
J. D.	12	68	48½	1	2,844	90	148	5	54	120	125	148	5	157	10	32	180
					3,218	90	168	10	78	360+	125	149	5	160	10	35	270
					3,154	90	168	10	78	150	123	158	5	158	5	35	300
					3,402	96	156	5	60	50	110	142	5	149	20	39	300
				2	6,432	88	168	5	80	270	114	142	5	160	20	46	300
					4,885	96	180	5	84	120	119	140	5	164	20	45	330
					6,066	96	180	5	84	116	162	5	..	166	10	45	390
				3	8,940	96	168	5	72	420	114	158	5	160	5	72	420
					8,660	102	168	5	66	60	109	156	5	160	5	51	450
					8,472	96	174	5	78	210	109	151	5	158	20	49	300

TABLE 14.—Effect of Different Types of Exercise on the Circulatory Reactions—(*Continued*)

Type of Exercise and Subject	Age in Years	Weight in Pounds	Height in Inches	Number of Min.	Foot-Pounds of Work	Pulse					Systolic Blood Pressure						
						Before Exercise	After Exercise				Before Exercise	After Exercise					
							Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Sec.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.
A. H.	10	60	50¼	1	2,907	96	148	10	52	120	114	162	5	164	5	50	270
					2,537	90	148	10	58	50	112	157	5	157	5	45	270
					2,660	96	168	5	72	50	109	134	5	145	30	36	360
				2	5,505	96	168	10	72	360	116	162	5	162	5	46	270
					5,690	90	144	5	54	420+	111	167	5	167	5	56	360
					5,568	96	168	5	72	360	116	148	5	152	10	53	420
				3	7,979	96	168	5	72	390+	114	143	5	155	30	41	390
					7,547	108	180	5	72	180	114	139	5	154	10	40	210
					8,525	96	180	5	84	510+	109	132	5	148	30	39	390
I. C.	8	57½	48	1	2,185	95	160	5	55	120	100	128	5	131	10	31	360
					2,145	95	160	5	65	240	100	121	5	126	5	26	300
				2	3,959	95	140	5	45	240	100	130	5	132	5	32	240
					3,918	95	150	5	55	180	100	127	5	132	20	32	390
				3	5,449	95	160	5	65	360	100	130	5	134	10	34	330
					6,032	90	150	5	60	360	97	125	5	127	5	30	360
B. M.	13	80	56	1	4,929	102	168	5	66	180	103	132	5	132	5	29	270
				2	7,620	100	168	5	68	180	96	130	5	138	20	42	270
D. H.	13	90	59¼	1	5,953	96	156	15	60	150	112	122	30	122	30	10	120
C. P.	13	....	....	1	4,451	108	...	..	..	...	...	...	..	145	30	35	360
G. P.	12	88½	58	1	4,931	84	156	10	72	270+	100	130	20	132	20	32	270
L. R. S.	12	80	56	1	2,148	105	144	5	39	40	89	120	10	120	10	31	270
W. T.	14	76	58	1	5,294	96	156	30	60	240+	109	130	30	130	30	21	240
R. B.	12	78	55¾	2	7,076	120	168	20	48	270	118	147	40	147	40	29	270
J. T.	12	76	55½	2	7,883	90	180	5	90	420+	94	100	5	109	50	15	300
M. R.	12	74	56	2	4,657	96	144	5	48	150+	110	142	30	142	10	32	
M. H.	12	74	56	2	10,890	90	180	10	90	420+	95	139	20	144	40	49	540+
A. G.	11	80	54¾	2	7,517	90	168	5	78	480	109	143	5	148	20	39	300
G. G.	6	47½	44	2	2,164	108	120	10	12	30	97	132	10	136	30	39	600
M. F.	14	85	59½	3	13,842	...	...	..	..	...	...	....	..	166	10	59	390
P. C.	13	92½	60¾	3	11,365	108	192	10	84	450	105	134	10	134	10	29	360
H. A.	10	67	53¼	3	8,155	108	168	5	60	300	125	166	5	147	20	49	270
D. Z.	13	99½	61	4	13,531	108	180	10	72	390	98	144	30	144	30	46	420
C. P.	12	91½	57½	4	12,776	105	160	20	55	600+	105	148	10	154	20	49	330
E. W.	11	60	52¼	4	13,010	102	180	10	78	240	113	147	5	149	5	36	300
A. F.	10	60	51	4	8,967	104	...	..	..	270	104	130	5	140	10	36	300
H. W.	9	61½	59	4	9,337	78	...	..	..	480+	101	153	5	162	20	61	300
S. B.	11	75½	56½	5	11,018	84	...	..	..	360+	102	122	5	129	30	22	330

an increase in swings. This is not borne out by Table 14; the majority of the cases showed the maximum readings within 30 seconds, only a small number at 40 and 50 seconds and none at 60 seconds or later.

Staircase Exercise.—In order to determine the effect of speed tests on the circulatory reactions, fifteen determinations were made, each child running up three flights of stairs. The average length of time for the run was fifteen seconds. The first blood pressure reading was taken within fifteen seconds after exercise. The amount of work performed by each child is recorded in Table 14. The pulse rate increased on an average of 47.1 beats per minute and the blood pressure 33.7 mm. The average reaction time of the pulse rate was 150 seconds, that of the blood pressure was 334 seconds. In 53.3 per cent. of the experiments (Table 15 C) the maximum reading occurred between 5 and 30 seconds. None of the experiments showed a delayed rise.

Ergometer.—Pulse Rate.—A number of children were allowed to ride the ergometer for periods of one, two, three and four minutes (Table 16). The children rode to the rythm of a metronome, so as to perform as equal amounts of work as possible. The average work for one minute was 4,279 foot pounds; for two minutes, 6,976 foot pounds; for three minutes, 9,690 foot pounds and for four minutes, 12,083 foot pounds. The rise in the pulse rate was 62.3 beats for one minute, 68.5 for two minutes, 65.8 for three minutes and 62.8 beats for four minutes. The reaction time of the pulse was 191 seconds, 319.5 seconds and 390 seconds, respectively, for the one, two, three and four minute exercises. Comparing the increase in the pulse rate after one minute with that after two minutes in the same subject, one finds an increase proportional to the work in four subjects, a decrease in one subject, while two subjects exhibit the same rise after the one minute as well as after the two minute exercise. Two subjects had a rise in pulse rate higher after three minutes exercise than after two minutes; in two subjects the pulse rate reached the same level, while one subject had a lower rise after three than after two minutes.

Blood Pressure (Table 17).—The blood pressure was determined simultaneously with the pulse rate. The rise of pressure was 36.5 mm. after the one minute, 39.8 mm. after two minutes, 31.2 mm. after three minutes and 42.6 mm. after four minutes. The time of maximum reading was 23.2 seconds, 28.1 seconds, 25 seconds and 36.2 seconds, respectively. The reaction time was 287 seconds, 339 (+) seconds and 330 seconds for the one, two and three minute exercise. In general, the blood pressure rises are higher after two minutes' exercise than after one minute; in the majority of the cases the blood pressure rise is greater after the three minute exercise than after the two minute exercise.

TABLE 15.—A. Reaction Time of Pulse After Different Types of Work

Sec.	Dumbbell				Stair-case	Ergometer			
	Body 10	Body 30	Body 60	Armlift, Exhaus-tive		1 Min.	2 Min.	3 Min.	Exhaus-tive
40	3	1	1	5	..	1	..	..	..
50	2	1	1	2	..	4	..	..	..
60	1	6	1	5	1	1	..	1	..
90	1	1	..	1	3	..	..	..	..
120	1	1	..	..	2	3	1	..	..
150	1	..	2	1	3	2	..	..	..
180	..	..	..	..	2	4	3	1	..
210	..	..	1	..	..	1	..	1	..
240	..	..	..	..	1	1	1	..	..
270	..	..	..	..	..	2	3	..	..
300	..	..	..	..	1?	..	..	1	..
360	..	..	..	..	..	1	2	3	..
390	..	..	..	..	..	..	..	1	..
420	..	..	..	..	..	..	1	1	..
450	..	..	..	..	1?	..	..	1	..
480	..	..	..	..	..	..	1	..	..
540	..	..	..	..	..	..	1	..	..
600+	..	..	..	..	..	..	1	2	All

B. Reaction Time of Blood Pressure After Different Types of Exercise

Sec.	Dumbbell				Stair-case	Ergometer			
	Bodylift			Armlift, Exhaus-tive		Exhaus-tive	1 Min.	2 Min.	3 Min.
	10	30	60						
40	..	..	..	..	..	..	..	..	..
50	..	..	..	..	..	..	1	..	..
60	..	..	..	..	..	..	..	..	..
90	1	..	..	..	..	..	1	..	..
120	2	..	..	..	..	..	..	..	..
150	5	3	1	3	..	3	..	..	..
180	2	4	..	5	..	6	1	..	..
210	1	..	1	1	..	18	..	..	1
240	..	1	..	1	..	17	1	2	1
270	..	2	1	..	1	17	9	4	1
300	..	1	1	1	2	23	4	5	2
330	..	..	1	..	2	21	..	1	1
360	..	..	1	..	3	15	6	2	2
390	..	1	2	1	2	18	2	3	2
420	..	..	..	..	2	12	..	1	1
450	..	..	..	..	..	3	..	..	1
480	..	..	..	..	1	..	..	..	..
510	..	..	..	..	..	1	..	1	..
540	..	..	..	..	..	1	..	..	..
570	..	..	..	..	..	1	..	..	..
600	..	..	..	..	..	1	..	..	..
Delayed time	..	..	..	1	2	18	..	..	1
No. of cases	11	12	8	13	13	158	25	21	12
Aver.	154	213	281	221	334	312	286	377	327

C. Time of Maximum Reading of Blood Pressure After Different Types of Work

Sec.	Ergometer			Dumbbell				Stair-case
	1 Min.	2 Min.	3 Min.	Body 10*	Body 30*	Body 60*	Arm-lift	
5	8	3	5	2	1	..	1	..
10	6	4	4	1	2	1	1	1
20	3	6	3	8	2	2	5	2
30	5	1	2	2	3	4	4	5
40	1	4	..	..	2	2	3	4
50	2	2	2	..	1	1	..	3
60	..	..	..	..	..	..	..	..
No. cases	25	18	16	12	11	10	14	15

* Number of swings.

TABLE 16.—Reaction of Pulse to Measured Amounts of Work

Subject	Age in Years	Load in Lbs.	1 Minute			2 Minutes			3 Minutes			4 Minutes			Remarks
			Foot-pounds of Work	Rise	Reaction Time, Sec.	Foot-pounds of Work	Rise	Reaction Time, Sec.	Foot-pounds of Work	Rise	Reaction Time, Sec.	Foot-pounds of Work	Rise	Reaction Time, Sec.	
J. C.	14	2	[1] 5,838	72	480+	[5] 9,941	96	540	[6] 12,465	96	660+	.....	..	...	Exp. 2 taken 1 hour after Exp. 1; Exp. 3 taken 45 min. after Exp. 2; Exp. 4 taken 2 hours after Exp. 3; Exp. 5 taken 30 min. after Exp. 4
		2	[2] 5,368	68	210										
		2	[3] 4,508	84	270										
		2	[4] 5,281	84	180										
H. B.	14	2	[1] 6,268	60	180	[3] 10,788	66	360	.....	..	...	.....	..	...	Exp. 2 taken 35 min. after Exp. 1; Exp. 3 taken 2 hours after Exp. 2; Exp. 4 taken 30 min. after Exp. 3
		2	[2] 6,199	68	360	[4] 11,624	68	300							
		2	9,748	68	480+										
D. G.	13	2	[1] 4,041	36	50	[2] 8,165	48	600+	[3] 11,875	36	360	14,886	60	300+	Exp. 2 taken right after Exp. 1; Exp. 3 right after Exp. 2; Exp. 5 right after Exp. 4; Exp. 6 right after Exp. 5
		2	[7] 3,793	40	150	[5] 8,248	45	180	[6] 12,044	65	450+				
		2	[4] 4,370	45	180				[8] 12,040		360+				
J. D.	12	1½	[1] 2,844	54	120	[5] 6,432	80	270	[6] 8,940	72	420	.....	..	...	Exp. 1, 2 and 3 taken on same day at 30 min. intervals; Exp. 4, following day; Exp. 5, 10 min. after Exp. 4; Exp. 6 right after Exp. 5; murmur after Exp. 1; Exp. 8 taken right after Exp. 7; Exp. 9 taken 30 min after Exp. 8; Exp. 10 taken right after Exp. 9
		1½	[2] 3,218	78	360+	[7] 4,885	84	120	[9] 8,660	66	60				
		1½	[3] 3,154	78	300+	[8] 6,066	84	270	[10] 8,472	78	210				
		1½	[4] 3,402	60	60										
A. H.	10	1½	[1] 2,907	52	120	[2] 5,505	72	360	[3] 7,979	72	390	.....	..	...	Exp. 2 taken right after Exp. 1; Exp. 3 taken right after Exp. 2; Exp. 4, 5 and 6 taken on the following day; Exp. 7, 8 and 9 taken one after the other
		1½	[4] 2,587	58	50	[5] 5,690	54	420+	[6] 7,547	72	180				
			[7] 2,660	72	50	[8] 5,568	72	390+	[9] 8,525	84	510+				
J. C.	8	1	[2] 2,185	55	120	[1] 3,950	45	240	[3] 5,449	65	360	.....	..	...	Exp. 2 taken right after Exp. 1; Exp. 3 right after Exp. 2; Exp. 4 and 5 taken 1 hour after Exp. 3
			[4] 2,145	65	240	[5] 3,918	55	180	[6] 6,032	60	360				
B. M.	13	2	4,929	66	180	7,620	68	180							
D. H.	13	2	5,963	60	150										
A. J.	12	2	4,981	72	270+	.....	..	...	.....	..	...	.....	..	...	Murmur
L. S.	12	2	2,148	38	40										
R. B.	6	¾	1,354	16	270										
W. T.	14	2	.....	..	...	5,294	60	240+							
B. B.	12	2	.....	..	...	7,076	48	270							
J. T.	12	2	.....	..	...	7,883	90	420							
M. R.	12	2	.....	..	...	4,657	48	150+	.....	..	...	.....	..	...	Discontinued; pain in hand
M. H.	12	2	.....	..	...	10,890	90	420+							
A. G.	11	2	.....	..	...	7,517	78	480							
G. G.	6	¾	.....	..	...	2,164	12	30	.....	..	...	.....	..	...	Arhythmia and extrasystole
M. F.	14	2	.....	..	...	.....	..	...	13,842	78	780				
P. C.	13	2	.....	..	...	.....	..	...	11,365	84	450				
H. A.	10	2	.....	..	...	.....	..	...	8,155	60	300				
D. Z.	13	2	.....	..	...	.....	..	...	.....	..	...	13,531	72	390	
C. P.	12	2	.....	..	...	.....	..	...	.....	..	...	12,776	55	600+	Arhythmia during first 10″
E. W.	11	1¼	.....	..	...	.....	..	...	.....	..	...	13,010	78	240	
A. F.	10	1¼	.....	..	...	.....	..	...	.....	..	...	8,957	34	270	
H. W.	9	1	.....	..	...	.....	..	...	.....	..	...	9,337	78	480+	
Average	.....	.....	4,279	62.3	191	6,976	68.5	319.5	9,690	65.8	390	12,083	62.8	(390)	R. B. and G. D. excluded

TABLE 17.—Reaction of Blood Pressure to Measured Amounts of Work

Subject	Age in Yrs.	Load in Lbs.	1 Minute					2 Minutes					3 Minutes					4 Minutes					Remarks
			Foot-pounds of Work	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	Foot-pounds of Work	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	Foot-pounds of Work	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	Foot-pounds of Work	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time Sec.	
J. C.	14	2	[1] 5,838	163	30	54	360	[5] 9,941	163	40	47	300	[6] 12,465	171	50	69	660+	.....	...	..	..	...	Exp. 2 taken 1 hour after Exp. 1; Exp. 3, 45 min. after Exp. 2; Exp. 4, 2 hours after Exp. 3; Exp. 5, 30 min. after Exp. 4
		2	[2] 5,368	155	20	43	270																
		2	[3] 4,508	149	50	40	240																
		2	[4] 5,281	149	5	41	270																
H. B.	14	2	[1] 6,268	157	5	57	390	[3] 10,788	161	40	55	390	.....	...	..	..	...	.....	...	..	..	...	Exp. 2 taken 35 min. after Exp. 1; Exp. 3, 2 hours after Exp. 2; Exp. 4, 30 min. after Exp. 3
		2	[2] 6,199	163	50	58	360	[4] 11,624	173	50	70	510											
		2	9,784	164	10	52	390																
D. G.	13	2	[1] 4,041	126	5	6	50	[2] 8,165	154	10	34	270	[3] 11,875	143	20	31	300	[5] 14,886	142	5	27	240	Exp. 2 taken right after Exp. 1; Exp. 3 right after Exp. 2; Exp. 5 right after Exp. 4; Exp. 6 right after Exp. 5
		2	[7] 3,793	134	40	24	360	[5] 8,248	132	20	22	300	[8] 12,044	142	5	27	240						
		2	[4] 4,370	134	10	24	300						[6] 12,040	133	30	23	390						
J. D.	12	1½	[1] 2,844	157	10	32	180	[5] 6,432	160	20	46	300	[6] 8,940	168	5	72	420	.....	...	..	..	...	Exp. 1, 2 and 3 taken on same day at 30 min. intervals; Exp. 4, following day; Exp. 5, 10 min. after Exp 4; Exp. 6 right after Exp. 5; murmur after Exp. 1; Exp. 8 right after Exp. 7; Exp. 9, 30 min. after Exp. 8; Exp. 10 right after Exp. 9
		1½	[2] 3,218	160	10	35	270	[7] 4,885	164	20	45	330	[9] 8,660	160	5	51	450						
		1½	[3] 3,154	158	5	35	300	[8] 6,066	166	10	45	390	[10] 8,472	158	20	49	300						
		1½	[4] 3,402	149	20	39	300																
A. H.	10	1½	[1] 2,907	164	5	50	270	[2] 5,505	162	5	46	270	[3] 7,979	155	30	41	390	.....	...	..	..	...	Exp. 2 taken right after Exp. 1; Exp. 3 right after Exp. 2; Exp. 4, 5 and 6, the following day; Exp. 7, 8 and 9, one after the other
		1½	[4] 2,537	157	5	45	270	[5] 5,690	167	5	56	360	[6] 7,547	154	10	40	210						
			[7] 2,660	145	30	36	360	[8] 5,568	152	10	43	420	[9] 8,525	148	30	39	390						
J. C.	8	1	[2] 2,185	131	10	31	360	[1] 3,959	132	5	32	240	[3] 5,449	134	10	34	330	.....	...	..	..	...	Exp. 2 taken right after Exp. 1; Exp. 3 right after Exp. 2; Exp. 4 and 5, 1 hour after Exp. 3
			[4] 2,145	126	5	26	300	[5] 3,918	132	20	32	390	[6] 6,032	127	5	30	360						
B. M.	13	2	4,929	132	5	29	270	7,620	138	20	42	270											
D. H.	13	2	5,953	122	30	10	120																
C. P.	13	2	4,451	145	30	35	360																
A. J.	12	2	4,931	132	20	32	270	.....	...	..	..	...	.....	...	..	..	...	... ..	...	..	..	...	Murmur
L. R.	12	2	2,148	120	10	31	270																
R. B.	6	¾	1,354	111	20	14	270																
W. T.	14	2	.....	...	..	..	...	3,294	130	30	21	240											
R. S.	14	2	.....	...	..	..	...	7,429	172	30	36	360											
R. B.	12	2	.....	...	..	..	...	7,076	147	40	29	270											
J. T.	12	2	.....	...	..	..	...	7,883	109	50	15	300											
M. R.	12	2	.....	...	..	..	...	4,657	142	10	32	...	.....	...	..	..	...	.....	...	..	..	...	Discontinued; pain in hand
M. H.	12	2	.....	...	..	..	...	10,890	144	40	49	540+											
A. G.	11	2	.....	...	..	..	...	7,517	148	20	39	300											
G. G.	6	¾	.....	...	..	..	...	2,164	136	30	39	600	.....	...	..	..	...	.....	...	..	..	...	Arhythmia and extrasystole
M. F.	14	2	.....	...	..	..	...	.....	...	..	..	...	13,842	166	10	59	390						
P. C.	13	2	.....	...	..	..	...	.....	...	..	..	...	11,365	134	10	29	360						
H. A.	10	2	.....	...	..	..	...	.....	...	..	..	...	8,155	174	20	49	270						
D. Z.	13	2	.....	...	..	..	...	.....	...	..	..	...	.....	...	..	..	...	13,531	144	30	46	420	
C. P.	12	2	.....	...	..	..	...	.....	...	..	..	...	.....	...	..	..	...	12,776	154	20	49	330	Arhythmia during first 10"
E. W.	11	1½	.....	...	..	..	...	.....	...	.	..	...	.....	...	..	..	...	13,010	149	5	36	300	
A. F.	10	1¼	.....	...	..	..	...	.....	...	..	..	...	.....	...	..	..	...	8,957	140	10	36	300	
H. W.	9	1	.....	...	..	..	...	.....	...	.	..	...	.....	...	..	..	...	9,337	162	20	61	300	
Aver.	..	..	4,287	145	18.2	36.5	287	6,998	121.2	25.7	39.8	339	9,690	151	17.3	30.1	369	12,083	148	15	42.3	330	

The comparison of the effect of various types of exercise on pulse rate and blood pressure shows their variability. Because of the inconstancy of the pulse rate no definite conclusions can be drawn. The reaction time seems to be more uniform than the increase in the rate. The reaction time is about equal in the staircase test and after one minute ergometer exercise. The pulse rate returns to normal within the shortest period after the dumbbell exercise.

The highest blood pressure rises are observed after sixty full swings of the dumbbells, the staircase exercise and the exhaustive arm exercise in the older children. In the majority of the cases, regardless of the kind of exercise and the amount of work performed, the maximum blood pressure occurs within thirty seconds. The reaction time seems to be more prolonged after the ergometer exercise and the staircase test than after the dumbbell exercises.

Maximum Physical Capacity of Children.—The maximum physical capacity was determined by means of the stationary bicycle, a detailed description of which was given in the first part of this paper. The experiments were limited to boys from 6 to 15 years of age. The muscular work of every boy was determined two or three times on successive days. The results are recorded in Tables 18 to 28. Only those experiments were accepted as accurate in which the child gave evidence of having performed its utmost. The load of work, controlled by manipulation of the screw on the brake and registered on the scale, was 2 pounds for children between 12 and 15 years of age, and from ¾ pound to 1½ pounds for the children aged from 6 to 12. Too great a load makes the riding of the bicycle difficult and joyless, and changes the type of exercise from one of endurance and speed into one of strength. The change of output following a change in load in one and the same subject is clearly demonstrated in Table 30. H. B. was able to produce 2.5 times as much against a load of 2½ pounds as against 3 pounds, and eight times as much against 2 pounds. In the case of H. T. the proportion of physical capacity, using a load of 3, 2½ and 2 pounds was 1, 2½ and 7, respectively. Other examples could be cited to prove the importance of the optimum load for each child. The question might be asked, why should the load not be decreased to a minimum if the difference in output evidently depends on the quantity of resistance? Two pounds was chosen for the optimum for the older boys because at that resistance the subject did not complain of difficulty in turning the wheel and any load under 2 pounds would have considerably prolonged the experiment. With the optimum load the children rode the bicycle for on an average of about fifteen minutes.

TABLE 18.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 6 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
B. D.	6	53.5	47¾	2 11,960	89	...	..	..	600+*	95	132	5	132	5	37	360	*Pulse 100 at 600″
				1 11,775	78	...	..	..	330+*	95	132	5	132	10	37	270	*Pulse 96 at 330″
G. H.	6	56	48	1 7,107	105	...	..	..	420+*	119	152	5	154	5	35	390	*Pulse 114 at 420″
				2 6,544	92	...	..	..	180	109	138	5	148	10	39	300	
A. T.	6	57	49	2 6,994	120	...	..	..	120	106	122	5	132	20	17	300	
				1 5,829	126	...	..	..	90	108	134	10	134	10	26	300	
M. E.	6	44.5	46	6,135	95	...	..	..	270+*	102	121	5	123	10	21	300	*Pulse 108 at 270″
E. B.	6	47.5	46½	5,540	95	...	..	..	390+*	91	127	5	133	30	18	360	*Pulse 108 at 390″
5 cases, 8 determinations	6	51.7	47 9/20	7,736	100	...	..	..	270+	103.1	132.3	5	134.4	12.5	30.3	322	

TABLE 19.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 7 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
U. W.	7	61.5	51	[2] 19,503	102	...	..	..	390+*	110	130	5	132	35	22	330	*Pulse 120 at 390″
				[1] 11,793	110	...	..	..	420+*	111	125	5	137	15	26	330	*Pulse 120 at 420″
C. J.	7	50.75	46¾	[1] 15,807	100	...	..	..	540+*	94	107	10	129	30	35	330	*Pulse 130 at 540″
				[2] 12,609	96	...	..	..	450+*	86	112	10	116	35	30	330	*Pulse 106 at 450″
C. K.	7	58	47½	[1] 15,510	80	...	..	..	360+*	98	125	10	129	15	31	390	*Pulse 100 at 360″
				[2] 13,206	80	...	..	..	450+*	95	116	5	124	15	29	390	*Pulse 110 at 450″
T. S.	7	58	47½	[2] 14,312	81	...	..	..	300+*	94	108	10	123	25	29	270	*Pulse 108 at 300″
				[1] 10,954	90	...	..	..	330	98	121	10	125	30	27	420	
M. B.	7	53.5	49¾	[2] 13,914	86	...	..	..	390+*	94	128	5	128	5	34	300	*Pulse 100 at 390″
				[1] 13,416	82	...	..	..	390	94	129	5	129	5	35	300	
H. S.	7	45	46¾	[2] 12,809	96	...	..	..	570+*	96	132	10	132	10	36	†	*Pulse 108 at 570″
				[1] 11,293	110	...	..	..	210	93	126	10	126	10	33	390	†Bl. Pr. 110-114 from 210-600″
L. D.	7	54.75	48	[2] 10,978	84	...	..	..	570+*	94	128	5	133	20	39	300†	*Pulse 96 at 570″
				[1] 9,430	105	...	..	..	240	105	128	5	153	40	48	300	†Bl. Pr. 101 from 300-540″
H. P.	7	58.5	48½	[2] 10,440	96	...	..	..	450+*	99	114	10	115	10	16	330	*Pulse 132 at 450″
				[1] 9,922	98	...	..	..	420+*	98	118	10	118	10	20	300	*Pulse 135 at 420″
E. B.	7	51	46¾	[2] 8,584	100	...	..	..	510	81	95	5	114	30	33	420†	*Pulse 130 at 390″
				[1] 7,294	115	...	..	..	390+*	106	139	5	139	5	33	270	†Bl. Pr. 93 from 420-600″
S. R.	7	47.25	46¼	[2] 6,600	90	...	..	..	180	81	108	5	109	15	28	330	
				[1] 6,229	92	...	..	..	300+*	85	116	5	116	5	31	390	*Pulse 110 at 300″
10 cases, 20 determinations	7	53.8	47 9/10	11,738	94.6	...	..	..	390+	95.6	120.2	5	126.4	18.2	30.7	353	

TABLE 20.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 8 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
I. P.	8	76.75	52½	[2] 32,458	85	200	5	115	360+*	114	141	5	149	20	35	390	*Pulse 120 at 360″
				[1] 17,684	107	...	..	..	540+*	113	140	5	149	10	36	420	*Pulse 115 at 540″
J. C.	8	57.5	48	[1] 24,651	96	156	5	60	600+*	101	128	5	134	20	33	390	*Pulse 102 at 600″
				[3] 20,003	96	168	10	72	600+*	102	118	5	129	10	29	300	*Pulse 114 at 600″
				[2] 18,966	96	180	5	84	480+*	108	126	5	130	20	28	180	*Pulse 108 at 480″
H. B.	8	79.5	52¾	[2] 21,663	90	160	5	70	360+*	102	142	5	142	5	40	330	*Pulse 105 at 360″
				[1] 15,205	98	...	..	..	360	107	134	10	136	10	29	240	
M. S.	8	60.25	49¾	[3] 19,588	96	168	5	72	480+*	80	105?	10	122	90?	33	390†	*Pulse 120 at 480″
				18,384	108	180	5	72	360+*	101	119	5	123	20	22	180	†Bl. Pr. 100 from 390-600″
				10,072	108	144	5	36	570	99	105	10	116	35	17	210	*Pulse 120 at 360″
G. S.	8	60.25	48	[3] 19,380	96	156	5	60	510+*	97	119	5	125	20	28	360	*Pulse 114 at 510″
				[1] 13,363	90	168	5	78	510+*	98	134	5	138	20	36	300	*Pulse 108 at 510″
				[2] 11,911	96	168	5	72	360+*	101	118	10	130	20	19	210	*Pulse 126 at 360″
J. B.	8	55.75	48½	[2] 18,380	80	...	..	..	570+*	99	120	5	128	20	29	270†	*Pulse 100 at 570″ †Bl. Pr. 107 from 270-600″
				[1] 16,766	76	...	..	..	570+*	104	116	10	119	60	15	240†	*Pulse 84 at 570″ †Bl. Pr. 105-109 from 240-600″
O. F.	8	55	49	[2] 17,247	102	...	..	..	600+*	93	111	10	123	30	30	330†	*Pulse 126 at 570″ †Bl. Pr. 110 from 330-600″
				[1] 11,165	90	...	..	..	270+*	102	129	10	133	40	31	330	*Pulse 115 at 270″
J. J.	8	64.25	51½	[2] 16,102	96	144	5	48	300+*	98	117	5	126	10	30	210	*Pulse 108 at 300″
				[1] 12,259	108	...	..	..	.....	99	118	5	128	20	29	180	
				[3] 11,089	96	156	5	60	540*	95	122	5	122	5	27	420	*Pulse 108 at 540″
W. P.	8	59	49	[1] 15,670	96	...	..	..	330+*	112	136	5	143	30	31	270	*Pulse 126 at 330″
				[2] 14,236	102	...	..	..	510+*	113	143	10	151	20	38	390	*Pulse 120 at 510″
M. G.	8	71.75	53½	[3] 14,802	95	...	..	..	240+*	87	103	10	107	30	19	300	*Pulse 110 at 240″
				[1] 13,840	82	...	..	..	330+*	96	113	5	127	30	31	270	*Pulse 110 at 330″
10 cases, 24 determinations	8	64	49.3	16,870	94.8	165.3	5	69.1	510+	101.2	123	5	126.2	21.9	28.9	293	

TABLE 21.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 9 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
M. B.	9	65.5	53	[2] 38,215	90	...	..	..	600+*	108	130	10	130	10	38	300	*Pulse 108 at 600″
				[1] 24,320	92	...	..	..	600+*	108	123	5	123	5	15	270	*Pulse 114 at 600″
H. G.	9	59	50½	[2] 36,893	86	...	..	..	520+*	100	113	10	116	20	16	360	*Pulse 106 at 520″
				[1] 20,869	104	...	..	..	450+*	107	133	10	140	40	33	360†	*Pulse 112 at 450″ †Bl. Pr. 117 at 360″; to remain there
H. W.	9	77.5	55½	[1] 33,906	90	144	5	54	450	104	128	5	128	5	24	150	Load 1 pound
				[2] 21,603	84	...	..	..	420+*	103	143	5	143	5	40	210	*Pulse 96 at 420″; load 1¼ pound
H. G.	9	61.5	52¼	29,460	96	...	..	..	600+*	103	130	5	130	5	27	330	*Pulse 100 at 600″
J. B.	9	79	56	[2] 28,800	96	...	..	..	360+*	105	124	5	124	5	19	150	*Pulse 120 at 360″
				[1] 12,325	108	...	..	..	600+*	120	140	10	149	20	29	240†	*Pulse 120 at 600″ †Bl. Pr. 127 at 240″; 127-132 from 240-600″
C. H.	9	67	53¼	[1] 26,270	90	168	5	78	600+*	112	131	15	133	10	21	210	*Pulse 102 at 600″
				[2] 19,378	96	...	..	..	390	93	130	5	130	5	37	270	
J. G.	9	58.5	51½	[2] 26,165	81	...	..	..	420+*	88	108	5	122	20	36	300	*Pulse 120 at 420″
				[1] 17,772	90	...	..	..	450	98	122	5	133	20	35	240	
R. O.	9	68.75	53½	[1] 20,998	102	...	..	..	510+*	98	138	5	138	5	40	570	*Pulse 126 at 510″
				[2] 16,937	116	...	..	..	390+*	101	135	20	131	10	34	360	*Pulse 125 at 390″
H. W.	9	61.5	59	[2] 17,724	90	...	..	..	420+*	101	129	10	133	40	32	300	*Pulse 102 at 420″
				[1] 12,610	88	..	..	..	420+*	110	130	5	143	30	33	210	*Pulse 100 at 420″
M. L.	9	57	51	[2] 15,251	84	...	..	..	570+*	91	108	10	119	30	28	270†	*Pulse 108 at 570″ †Bl. Pr. 98-101 from 270-600″
				[1] 12,577	87	...	..	..	570+*	91	113	5	129	30	38	300†	*Pulse 102 at 570″ †Bl. Pr. 98-108 from 300-600″
10 cases, 19 determinations	9	65.25	54	21,608	93.2	...	..	..	510+	102	132	5-10	131	16.6	30.4	282	

TABLE 22.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 10 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
H. S.	10	74	55¼	[2] 57,331	93	...	..	..	510+*	93	112	5	119	20	26	270	*Pulse 108 at 510″
				[1] 45,752	96	192	5	96	390+*	107	127	5	127	5	20	300	*Pulse 144 at 390″
J. H.	10	104.5	56¼	[2] 40,202	93	...	..	..	600+*	107	142	5	147	30	40	420	*Pulse 108 at 600″
				[1] 30,378	100	180	5	80	600+*	106	142	5	142	5	36	360	*Pulse 120 at 600″
H. A.	10	67	53¼	[1] 36,444	100	180	5	80	600+*	117	158	5	168	30	51	360	*Pulse 114 at 600″; murmur
				[2] 29,517	87	...	..	..	450+*	119	143	10	158	30	39	300	*Pulse 120 at 450″
L. C.	10	63.75	53¾	[2] 35,531	85	...	..	..	330+*	97	115	20	119	30	22	240	*Pulse 125 at 330″
				[1] 24,337	110	...	..	..	390+*	100	121	20	121	20	21	210	*Pulse 140 at 390″
A. H.	10	60	50¼	[2] 28,750	90	100	5	90	600+*	107	154	5	154	5	47	330	*Pulse 120 at 600″
				[1] 24,319	106	192	5	86	600+*	118	149	10	161	30	43	360	*Pulse 120 at 600″
G. C.	10	67	52¾	[2] 22,500	108	...	..	..	480+*	92	122	5	127	10	35	270†	*Pulse 132 at† 180″ †Bl. Pr. rem ins at 102; other children presesnt
				[1] 21,611	105	...	..	..	600+*	100	120	15	124	40	24	240	*Pulse 126 at 600″
F. C.	10	71	55	[2] 22,469	84	...	..	..	480+*	99	148	5	148	5	49	390	*Pulse 108 at 480″
				[1] 17,679	90	...	5	..	600	114	148	5	157	30	46	420	
A. F.	10	64	51	[2] 20,933	90	144	10	54	390+*	101	128	5	128	5	27	210	*Pulse 120 at 390″
				[1] 20,275	96	...	..	..	600+*	103	126	10	137	40	34	240	*Pulse 108 at 600″
C. J.	10	91	53¾	[1] 9,898	108	168	5	60	510+*	109	142	5	143	5	34	210	*Pulse 120 at 510″
				[2] 7,318	102	156	5	54	300	106	148	5	150	5	42	180	
9 cases, 18 determinations	10	73.6	53½	27,518	96.8	164	5	75	510+	105.3	135.8	5	140.6	19.2	35.3	296	

TABLE 23.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 11 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
P. H.	11	89.5	57½	[1] 57,123	86	...	..	..	510+*	103	135	5	150	25	47	330	*Pulse 126 at 510″
				[2] 48,103	87	...	..	..	390	103	128	5	138	10	35	360	
G. D.	11	70	52¾	[2] 54,552	78	...	..	..	510+*	107	132	5	137	20	25	390	*Pulse 108 at 510″
				[1] 36,164	80	...	..	..	.....	119	142	5	149	30	30	450	
S. B.	11	75	55½	[2] 40,296	96	...	..	..	420+*	103	121	10	125	60	22	390	*Pulse 132 at 420″
				[1] 35,773	91	...	..	..	570+*	103	129	15	129	15	26	240	*Pulse 108 at 570″
H. R.	11	73.75	52¾	[1] 37,235	90	...	..	..	510+*	96	130	10	131	20	35	390	*Pulse 114 at 510″
				[2] 35,418	91	...	..	..	510+*	98	108	5	117	20	19	360	*Pulse 126 at 510″
A. G.	11	80	54¾	33,831	86	...	..	..	600+*	111	137	5	137	5	26	330	*Pulse 102 at 600″
P. M.	11	82	54¾	[2] 32,100	97	...	..	..	390+*	103	124	5	128	10	25	270	*Pulse 102 at 390″
				[1] 30,974	101	...	..	..	.....	115	140	5	142	15	37	240	
E. R.	11	92.5	60½	31,706	100	...	..	..	120	101	126	5	132	10	31	270	Bicycle too small; no dyspnea
E. W.	11	60	52¼	[2] 27,574	90	...	..	..	510+*	100	140	10	150	35	50	540	*Pulse 114 at 510″; tremor
				[1] 17,056	102	192	5	90	540+*	108	142	5	151	50	43	390	*Pulse 108 from 330-540″
V. B.	11	74	55¼	[2] 24,918	86	...	..	..	600+*	91	122	5	122	5	31	300†	*Pulse 102 at 600″ † Bl. Pr. 95 at 300″; 97-203 from 300-600″; dyspnea after exercise very prolonged
				[1] 23,015	87	...	..	..	600+*	96	131	5	137	50	43	240†	*Pulse 102 at 600″ †Bl. Pr. 104-109 from 240-600″
A. F.	11	146	62¼	[2] 19,040	96	180	5	84	400+*	117	158	5	158	5	47	†	*Pulse 108 at 13 min.
				[1] 13,820	108	190	30	84	600+	110	158	30	167	50	57	300	†Bl. Pr. 125 at 300″; 22 and 23 after 13 min.
10 cases, 18 determinations	11	84.3	55⅛	33,261	91.8	...	..	..	510+	110.4	133.5	5	138.8	18.6	35.5	350	

TABLE 24.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 12 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
J. D.	12	68	48½	[1] 48,048	96	192	5	96	600+*	113	140	5	158	40	45	570	*Pulse 114 at 600″
				[2] 40,275	84	168	5	84	600+*	113	148	5	158	20	45	510†	*Pulse 108 at 600″ †Presence of principal might have delayed drop of blood pres.
H. R.	12	75	56½	[2] 56,881	90	216	5	126	600+*	103	138	5	144	50	41	420	*Pulse 120 at 600″
				[1] 40,481	90	192	5	102	420+*	101	138	5	155	30	54	390	*Pulse 120 at 420″
A. M.	12	109	61½	[2] 44,837	96	180	5	84	600+*	136	188	5	188	5	52	330	*Pulse 120 at 600″
				[1] 37,740	72	180	5	108	450+*	129	135	5	155	30	27	210†	*Pulse 126 at 450″ †Bl. Pr. below normal at 240″, 116 at 450″
				[2] 26,240	90	156	10	66	900+*	132	169	20	169	20	37	150	*Pulse 120 at 900″, 90 at 30 minutes
D. G.	12	100	58¼	[1] 44,514	115	180	5	65	420+*	115	126	5	138	30	23	210	*Pulse 132 at 420″
				[2] 30,139	112	168	5	56	540+*	112	130	5	132	5	20	210	*Pulse 115 at 540″; murmur
J. T.	12	76	55½	[1] 30,709	84	...	..	..	360+*	102	124	5	124	5	22	180	*Pulse 126 at 360″; Exp. 1 against 1¼ pounds
				[2] 12,622	104	...	..	..	420+*	100	121	10	130	30	30	360	*Pulse 120 at 420″; Exp. 2 against 1¾ pounds
T. B.	12	89	54¾	[1] 24,299	84	156	10	72	480+*	102	107	15	127	50	25	240	*Pulse 96 at 480″
				[2] 29,224	90	156	5	66	390+*	100	115	5	134	20	34	300	*Pulse 102 at 390″
J. B.	12	88.5	58	[2] 28,711	66	...	..	..	600+*	98	129	5	136	20	43	360	*Pulse 82 at 600″
				[1] 14,836	60	...	..	..	600+*	99	124	10	132	20	33	270	*Pulse 78 at 600″
M. S.	12	81.5	..	25,452	87	...	..	..	600+*	97	120	10	133	50	36	450	*Pulse 120 at 600″
A. J.	12	74	57¼	[1] 22,970	84	156	5	72	600+*	115	152	5	152	5	37	270	*Pulse 96 at 600″; murmur
				[2] 20,858	66	132	5	66	540+*	116	140	5	147	20	31	210	*Pulse 84 at 540″
B. B.	12	62.5	52¾	[2] 18,407	84	156	10	72	540+*	109	155	5	159	10	50	390	*Pulse 108 at 540″
				[1] 14,009	96	180	5	84	540+*	112	148	5	149	5	36	240	*Pulse 108 at 540″
A. G.	12	80.5	60	[1] 16,904	84	168	30	84	240+*	107	134	30	140	60	33	240+†	*Pulse 108 at 240″ †Bl. Pr. 114 at 240″ (one of first Exp. made)
				[2] 14,667	84	168	5	84	480+*	107	128	5	145	40	38	270	*Pulse 96 at 480″
M. R.	12	74	56	16,790	108	132	30	24	240	108	152	30	152	30	44	450	
12 cases, 23 determinations	12	84.1	56	29,216	87	171.8	5	81.6	600+	110	136.8	5	144.2	24.3	36.2	323	M. R. excluded

TABLE 25.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 13 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
C. J.	13	95	59	[4] 70,735	96	180	5	82	600+*	95	133	5	146	40	51	450	*Pulse 120 at 420-720″
				[3] 49,954	96	192	5	96	390+*	96	148	5	148	5	52	300	*Pulse 120 at 390″
				[2] 42,196	96	192	5	96	600+*	105	151	3	151	5	46	240	*Pulse 126 at 600″
				[1] 28,339	96	168	5	72	390	94	150	10	150	10	56	300	
A. P.	13	112.5	62	69,354	108	180	10	72	1,020+	113	146	10	146	10	33	240	
L. W.	13	124.5	66	[2] 62,534	102	180	5	78	1,560+*	110	162	5	162	5	52	300	
				[1] 35,571	84	168	10	84	600+*	105	145	20	147	20	42	240	
L. R. S.	13	83	60¾	46,953	96	120	15	24	180	91	120	10	120	10	29	300+*	*Bl. Pr. 101 at 300″; uncomfortable; discont.
M. W.	13	100	67½	[2] 42,807	96	180	5	84	420+*	112	154	5	158	20	48	210	*Pulse 114 at 420″
				[1] 30,321	84	156	10	72	300+*	115	141	20	141	20	28	210	*Pulse 108 at 300″
B. M.	13	80	56	[2] 42,293	90	180	5	90	390+*	98	120	5	130	50	32	390	*Pulse 114 at 390″; Exp. 2 against 1¼ pounds
				[1] 14,281	96	180	10	84	480+*	100	130	10	137	30	37	480+†	*Pulse 115 at 480″; Exp. 1 against 2 pounds †Bl. Pr. 116 at 480″
D. Z.	13	99.5	61	40,247	108	192	5	84	420+*	95	111	5	126	10	31	240	*Pulse 132 at 570″
E. L.	13	75	55½	30,374	76	192	10	116	360+*	96	128	10	128	10	32	210	*Pulse 132 at 360″
P. C.	13	92.5	60¾	[2] 29,041	108	192	5	86	360*	108	126	5	126	5	21	210	*Pulse 108 at 360″
				[1] 29,021	96	204	10	108	600	108	137	10	137	10	26	420	
M. S.	13	85	59¾	26,955	108	180	10	72	420	98	125	10	128	20	30	420	
C. S.	13	90	60¼	24,764	78	180	10	102	1,020+*	106	150	10	154	20	50	600†	*Pulse 96 at 17 min., 78 at 42 min.; murmur †Bl. Pr. 115 at 330″; remained there until 570″; 110 at 600″
B. C.	13	88.5	60¼	15,733	108	180	5	72	420	105	124	10	133	40	28	390	
D. H.	13	90	59¼	[1] 10,627	84	156	10	72	300+*	104	142	20	142	20	38	300	*Pulse 108 at 300″; neurotic boy
				[2] 8,434	90	168	5	78	420+*	102	134	5	138	20	36	330	*Pulse 108 at 420″
13 cases, 21 determinations	13	86.4	60.6	38,749*	85	178	5-10	82	390+	103	137	5-10	140	18.1	38	300	*Last 2 cases excluded

TABLE 26.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 14 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
H. B.	14	118	63	[2] 86,500	78	144	40	66	270+*	113	165	20	167	20	54	300	*Pulse radial, 84 at 270″; exp. made 1½ hours after exp. listed below
				[1] 77,378	84	132	10	48	180+*	116	158	10	158	10	42	330	*Pulse 94 at 180″
				[2] 66,506	96	192	5	96	360+*	109	146	5	149	10	40	240	*Pulse 132 at 300″
R. G.	14	122	63¼	83,082	84	144	30	60	300	122	172	30	172	30	50	420	
J. C.	14	93	60¾	[1] 76,290	72	140	30	68 ?	*	113	141	30	145	60?	32	180	*Pulse 96 at 210″; one of the first exp. made
				[2] 51,404	84	192	5	108	1,020+*	111	143	10	149	20	40	180	*Pulse 108 at 17 min.
W. T.	14	76	58	[2] 55,346	80	156	5	76	600+*	109	138	5	138	5	29	270	*Pulse 108 at 600″
				[1] 40,276	78	156	10	78	600+*	108	142	5	146	10	38	330	*Pulse 108 at 600″
A. F.	14	85.5	58¾	[2] 51,441	96	180	5	84	660+*	99	132	5	132	5	33	330	*Pulse 114 at 660″
				[1] 50,310	90	156	10	66	690*	96	133	10	134	10	38	360	*Pulse 97 at 690″
J. B.	14	109	63	[1] 46,705	108	168	10	60	960*	116	127	10	136	20	20	420	*Pulse 126 at 960″; murmur after exercise
				[2] 45,511	96	192	5	96	510+*	123	150	5	159	50	59	330	*Pulse 120 at 510″
M. H.	14	75	56	37,202	74	180	5	116	600+*	103	139	5	148	20	36	270 or 300	*Pulse 114 at 600″
M. S.	14	120	65	[2] 36,035	102	180	5	80	600+*	121	172	5	172	5	51	330	*Pulse 114 at 10-15 min.
				[1] 23,452	96	192	10	96	600+*	129	167	10	167	10	32	420	*Pulse 114 at 14 min.; murmur
E. R.	14	97	59	25,865	100	180	10	80	600+*	102	138	10	142	20	40	330	*Pulse 108 at 600″; 102 at 12 min.
C. H.	14+	93.5	59¾	[1] 25,141	81	168	10	87	600+*	113	156	10	158	10	45	330	*Pulse 96 at 660″
				[2] 18,314	102	180	10	68	420*	118	150	20	155	30	37	270	*Pulse 108 at 420-720″
F. L.	14	109.5	61	24,952	102	180	5	78	540+*	114	147	5	153	40	39	420	*Pulse 132 at 540″; murmur
H. P.	14	98	63	20,730	81	168	10	87	540+*	93	132	20	132	20	39	240	*Pulse 108 at 540″
M. K.	14	97.5	58½	[2] 20,579	96	192	5	96	600+*	109	144	5	153	30	44	360	*Pulse 120 at 600″; murmur
				[1] 15,165	108	180	10	93	450	103	142	10	144	20	43	240	
M. F.	14	85	59½	8,248	90	168	20	78	780	109	166	10	166	10	57	390	*Pulse 102 at 450″
14 cases, 23 determinations	14	97.7	60⅝	42,049	86	170.5	5-10	81.3	540+	106.5	145.2	5-10	147.4	18.4	41	313	

TABLE 27.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Age 15 Years

Subject	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
D. F.	15	...	..	108,762	96	192	5	96	300+	113	142	5	146	10	33	240	*Pulse 132 at 300″
H. F.	15	116	63	68,701	96	192	10	96	300+*	116	150	20	150	20	34	210	*Pulse 96 at 570″; subject collapsed at 2d experiment, having done 123,599 ft. lbs.
P. L.	15	110	62½	45,820	110	192	5	82	960+*	128	159	5	166	20	38	360	*Pulse 120 at 16 min.; 144 at 360″
				25,886	96	180	5	84	540+*	129	153	5	168	60	39	270	*Pulse 108 at 540″; 126 at 360″
3 cases, 4 determinations	15	113	63	62,295	99	189	5	90	300+	124	154	5	158	27.5	36	270	

TABLE 28.—Effect of Maximum Amount of Work in Foot-Pounds on Pulse and Systolic Blood Pressure. Ages 15 to 6 Years

Number of Cases	Age in Years	Weight in Pounds	Height in Inches	Foot-Pounds of Work	Pulse					Systolic Blood Pressure							Remarks
					Before Exercise	After Exercise				Before Exercise Mm.	After Exercise						
						Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.		First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.	
3 cases, 4 determinations	15	113	63	62,295	99	189	5	90	300+	124	154	5	158	27.5	36	270	
14 cases, 23 determinations	14	97.7	60.6	42,049	86	170.5	5-10	81.3	540+	106.5	145.2	5-10	147.4	18.4	41	313	
13 cases, 21 determinations	13	86.4	60.6	38,749*	85	178	5-10	82	390+	103	137	5-10	140	18.1	38	300	*Two cases excluded
12 cases, 23 determinations	12	84.1	56	29,216	87	171.8	5	81.6	600+	110	136.8	5	144.3	24.3	36.4	323	Case of M. R. excluded
10 cases, 18 determinations	11	84.3	55.8	33,261	91.8	...	..	..	510+	110.4	133.5	5	138.8	18.6	35.5	350	
9 cases, 18 determinations	10	73.6	53.5	27,518	96.8	164	5	75	510+	105.3	135.8	5	140.6	18.1	35.3	297	
10 cases, 19 determinations	9	65.25	54	21,608	93.2	...	..	..	510+	102	132	5-10	131	16.6	30.4	282	
10 cases, 24 determinations	8	64	49.3	16,870	94.8	165.3	5	69.1	510+	101.2	123	5	126.2	21.9	28.9	293	
10 cases, 20 determinations	7	53.8	47.9	11,738	94.6	...	..	..	390+	95.6	120.2	5	126.4	18.2	30.7	353	
5 cases, 8 determinations	6	51.7	47.45	7,736	100	...	..	..	270+	103.1	132.3	5	134.4	12.5	30.3	322	

Close observation of physical signs of exertion was made throughout the experiment. Flushing, breathlessness, slight and severe perspiration were recorded (Fig. 4) as soon as they appeared. Fatigue of the legs usually set in after the first two or three minutes of exercise but disappeared soon after. It reappeared on prolonged exercise. Toward the end of the ride, the majority of children complained about muscular fatigue, only a few complained of precordial distress. The degree of breathlessness, subjectively, was not in proportion to the amount of work nor the state of exhaustion. Of 200 experiments on 101 subjects, eight developed a murmur at the end of exercise. The murmurs were short in duration, systolic in time and heard only at the apex. Four of the murmurs were cardiopulmonary, while the other four were uninfluenced by respiration. They all disappeared within ten minutes after cessation of work.[10]

The fourth column in Tables 18 to 28 represents the maximum output in foot pounds of children between 6 and 15 years of age. It can be seen that the results vary in different children of the same age and are also inconstant for one and the same child at different times. This applies only to children past 8 years of age. Under 8, the variability is only about 1,000 foot pounds. In children above 8, no two experiments result in the same quantity of work, although the same external conditions, as time of day and relation to food, were carefully observed in successive experiments. Repetition usually increased a child's output. Will power, depending on the mood, seemed to play a great part in the total amount of work. The individual variance amounts to less than 1,000 foot pounds for children of 6 years to about 1,300 foot pounds at 7 years, 5,000 foot pounds at 8 years, on an average of 8,000 foot pounds from 9 to 11 years and more than 10,000 foot pounds from 11 to 15 years. Generally speaking, only about 31 per cent. of all children examined showed an individual variation of less than 2,000 foot pounds. It must be borne in mind that the results obtained are only of comparative value.

Relationship Between Physical Output and Certain Physical Factors.—What factors determine the physical capacity of a person? Is the efficiency in children proportionate to their height and weight? Does good physical development expressed in the circumference of the chest and thigh assure one of greater physical endurance? Do the advocates of physical training justly assume that training is followed by increased muscular efficiency?

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10. The formula used for calculating the amount of foot pounds per minute is as follows: number of revolutions per minute $\times$ load $\times \frac{63.025''}{4 \times 12} \times 2\pi$; $\frac{63.025''}{4 \times 12}$ represents the length of the beam.

Effect of Height and Weight on Physical Capacity.—The heights and the weights of all the children were grouped into one inch and five pound divisions, respectively. The weights are but relative, since the children were not undressed. Table 29 B shows a steady and almost constant increase of physical capacity in children from 45 to 51 inches in height. Such a constancy in increase is not apparent in children taller than fifty-one inches. Table 29 A shows a similar relationship between weight and working capacity.

Up to 9 years of age the physical capacity seems to be in proportion to the height and weight. In older children, however, the physical capacity is not influenced by these two factors.

Effect of Physical Development on Physical Capacity.—In Figure 5 can be noted the relationship between the amounts of work and the

TABLE 29.—Relation Between Weight and Capacity for Work in Normal Children, Age 6 to 15 Years

A			B		
Number of Cases	Weight in Pounds	Amount of Work in Foot-Pounds	Number of Cases	Height in Inches	Average Work in Foot-Pounds
3	125-121	53,179	6	63	58,770
2	120-116	36,475	3	62	43,520
1	115-111	58,897	3	61	34,756
4	110-106	36,496	5	60	36,621
1	105-101	10,126	5	59	33,609
5*	100- 96	32,292	3	58	34,503
6	95- 91	37,179	5	56	36,817
4	90- 86	37,513	11	55	35.417
6	85- 81	35,509	9	54-53	27,711
7	80-176	37,711	7	52	30,470
9	75- 71	33,457	7	51	20,956
7	70- 66	31,099	6	50-49	15,566
4	65- 61	17,533	7	48	11,490
12	60- 56	16,116	5	47-45 incl.	6,680
6	55- 51	12,089			
5	50- 45	6,034			

circumference of the chest. Each dot represents the arithmetical means of the results of two or three experiments in the same child. The straight line is the actual curve of the arithmetical means of the maximum output. The dotted line represents the theoretical curve obtained by smoothing the humps which are seen in the straight line. These curves show a definite relation between the circumference of the chest and maximum physical capacity.

Also in Figure 6 we find a definite relation between the circumference of the thigh and the amount of work in foot pounds. The curve running through the dots is a smoothed one based on the arithmetic averages of maximum output at 1 cm. measurements of the thigh.

Effect of Training on Physical Capacity.—To determine the effect of training on the capacity for work the subjects were divided into two

groups: those who knew how to ride a bicycle and those who did not. It is, of course, obvious that such a comparison must be lacking in accuracy since the degree of training was not taken into account. It was found, in general, that children who rode a bicycle surpassed in physical capacity those who did not. Bicycle riding increased the physical efficiency 30 per cent. at 8 years, 20 per cent. at 9 years, 48

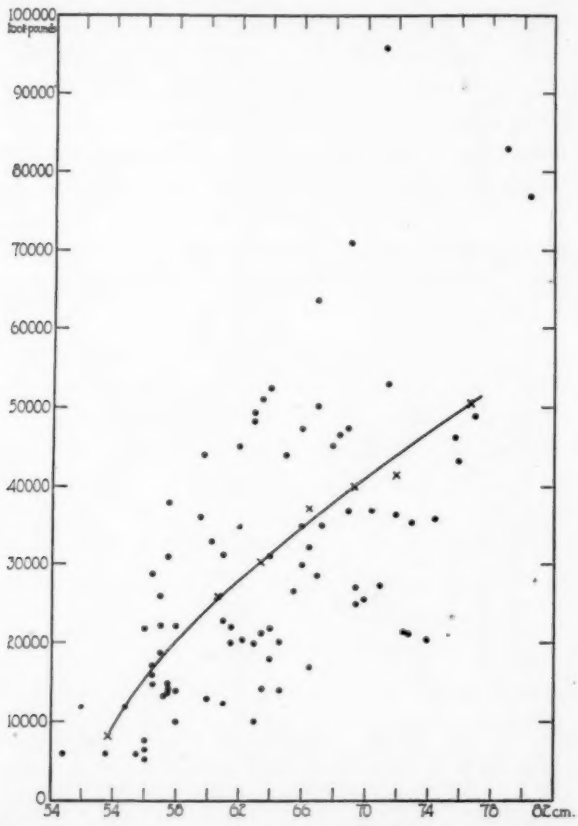

Fig. 5.—Relationship between circumference of chest and maximum physical capacity.

per cent. at 10 years, 7 per cent. at 11 years, 42 per cent. at 12 years, 53 per cent. at 13 years, and 36 per cent. at 14 years.

Effect of Vital Capacity on Physical Capacity.—The vital capacity of the children examined ranged from 1,000 to 3,550 c.c. Figure 7 shows the close relation between vital capacity divided into groups of 300 c.c. and the maximum physical output. In Figure 7 the straight line represents the output in foot pounds intersecting corresponding points of vital capacity at 300 curve intervals. The dotted line is the theoretic smoothed curve.

The effect of exercise on vital capacity was also determined in six children from 9 to 14 years of age. Each of the subjects had to perform his utmost on the ergometer on three successive days, and on the fourth day the subject was allowed to run up three flights of stairs as fast as possible, three times in succession. In every instance

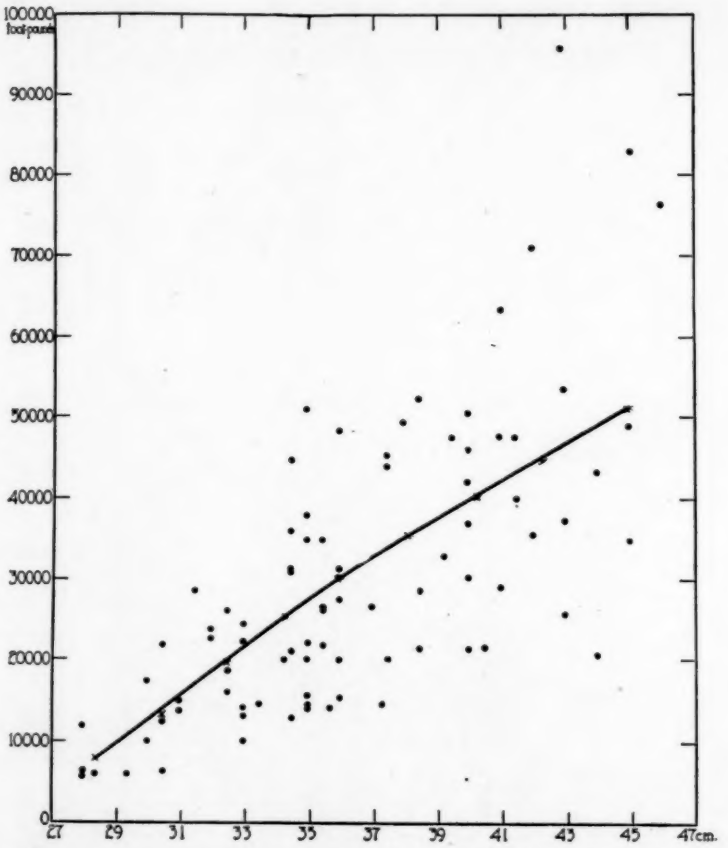

Fig. 6.—Relationship between circumference of thigh and maximum physical capacity.

the vital capacity showed neither a decrease nor an increase over the vital capacity taken each time right before exercise. This is significant in the presence of marked dyspnea and fatigue.

Effect of Age on Physical Capacity.—A most definite relation exists between physical capacity and age. Figure 8 shows the increase of maximum working capacity with age. The curve represents a straight line slightly broken at 10 years of age. Calculations revealed that the relationship between age and maximum physical work can

be expressed in two empirical formulas, one pertaining to children from 6 to 10 years of age, the other applicable to children from 11 to 14 years.

Formula I: Maximum physical output (age from 6 to 10 years) = 1,000 (5.45 age — 25.3).

Formula II: Maximum physical output (age from 11 to 14 years) = 3,000 × age.

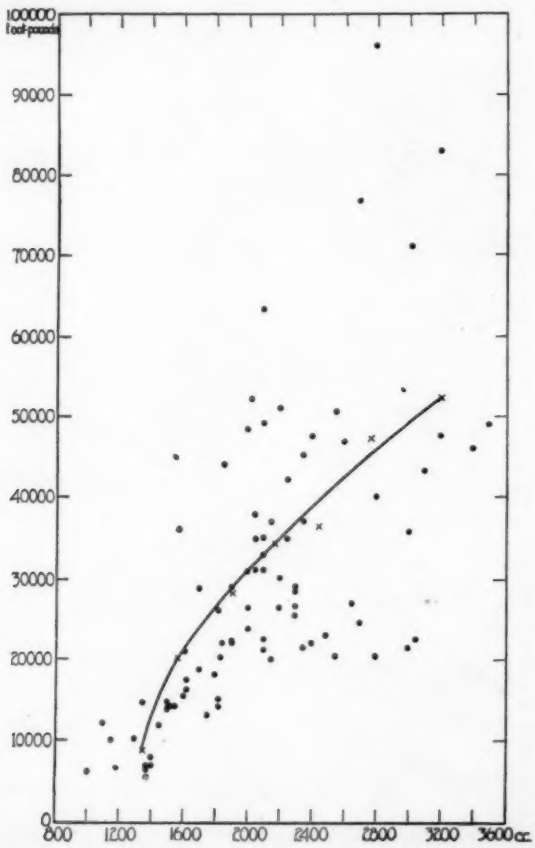

Fig. 7.—Relationship between vital capacity and maximum physical capacity.

Effect of Maximum Amount of Work on the Pulse Rate.—The first reading of the pulse rate was taken within from five to ten seconds after cessation of exercise. During the first minute counts of the pulse rate were repeated at intervals of ten seconds (five seconds being devoted for each reading). From the second minute on, the pulse rate was recorded in one-half minute periods for ten minutes. The maximum reading in column 7 of Tables 18 to 28 is the equivalent of the first reading taken, multiplied by twelve. It, therefore, does

not represent the true rate of the pulse for the entire first minute. The true rate for the first minute can be obtained by adding up all the readings (about six) taken during the first minute. This was only carried out in subjects with a maximum reading above 165. This figure was taken as the upper limit because of the claim of other investigators who considered a rate above 160 as indicative of myocardial insufficiency. Forty-nine children, aged from 8 to 15

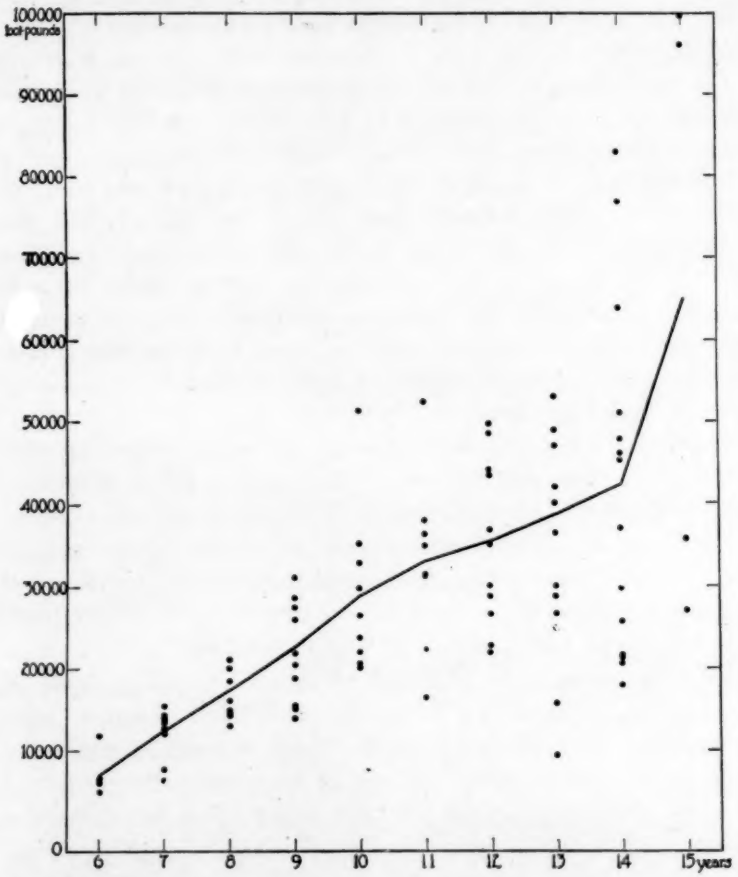

Fig. 8.—Relationship between age and maximum physical capacity.

years, showed a maximum reading above 165 per minute. It was found that of the forty-nine children with a maximum reading above 165, only twenty-one had an actual pulse rate of 165 and over during the first minute following the cessation of work. Of thirteen boys, aged 14, four had a pulse rate from 165 to 169 (I. C., A. F., C. H. and M. K.), one of 171 (M. K.) and another of 180 (M. S.). In seven of the 13 year old boys a pulse rate over 165 was found: From

165 to 169 in three cases; three with a rate of from 170 to 175 and one with a pulse of 184 (E. L.). Among the 12 year old children there were two with a pulse rate from 165 to 169 (I. B., A. M.), one with a pulse of 170 (D. E.) and another boy with a pulse rate as high as 193 (H. R.). Two boys, aged 11, had counts of 172 (E. W.) and 178 (A. F.). One 10 year old boy (A. H.) had a pulse rate of 180 and another one (T. P.), aged 8, had the same rate. None of these children showed any signs of overexertion, such as nausea, fainting or dull heart sounds. These results would indicate that a pulse rate above 160 after exercise is not incompatible with a normal myocardium.

The rise in pulse rate after exercise varies from as low as forty-eight to as high as 116. The increase in the pulse rate does not seem to be parallel with the increase in work in exhaustive exercises.

For instance, H. B., aged 14, showed the highest rise (96) in the experiment in which he performed 20,000 foot pounds less than in the experiment that caused his pulse rate to rise only seventy-eight beats. C. T., aged 13, had a maximum rise of twelve beats lower in an experiment 28,000 foot pounds higher than in a following experiment. More instances could be cited to show that a decrease in work is not necessarily followed by a decrease in the rise of the pulse rate and vice versa.

In general, there is a slight average increase of the rise with age (Table 28). The reaction time of the pulse is of no clinical value. In the earlier experiments it was noticed that practically none of the pulse rates returned to normal within ten minutes after cessation of work. In two experiments the reaction time of the pulse was thirty and thirty-five minutes, respectively. Therefore, the determination of the pulse rate was omitted in the later experiments.

Effect of Maximum Amount of Work on the Systolic Blood Pressure.—As referred to previously, the blood pressure cuff was kept partially inflated during the last three seconds of exercise so as to obtain the first reading as soon as experimentally possible after stopping. The majority of the first blood pressure readings were, therefore, taken within five seconds, a smaller number within ten seconds.

Rise of Blood Pressure After Exercise.—A comparison of the increases in systolic blood pressure obtained in the same subject after different amounts of maximum work revealed the interesting fact that in only about one half of all the experiments was there a higher rise after larger amounts of work. The most striking examples are P. L., aged 15, who after accomplishing 45,820 foot pounds had a rise in blood pressure of 20 mm. and after 25,886 foot pounds of 60 mm.; I. B., aged 14, had a rise of 20 mm. after 46,705 foot pounds

TABLE 30.—Effect of Load on Working Capacity

Subject	Age in Years	Weight in Lbs.	Height in Inches	Load in Lbs.	Foot-Pounds of Work	Pulse					Blood Pressure						
							After Exercise					After Exercise					
						Before Exercise	Maximum Reading	Time of Maximum Reading, Sec.	Rise	Reaction Time, Sec.	Before Exercise	First Reading, Mm.	Time of First Reading, Sec.	Maximum Reading, Mm.	Time of Maximum Reading, Sec.	Rise, Mm.	Reaction Time, Sec.
H. B.	14	118	63	3	9,684	102	180	5	78	480+	112	150	5	164	40	52	450
				2½	23,826	102	180	10	78	660	107	144	5	153	30	46	600
				2	66,506	96	192	5	96	360+	109	146	5	149	10	40	240
C. I.	13	95	59	3	7,530	90	144	10	54	420	96	159	10	159	10	63	420
				2½	17,438	96	168	10	72	600+	95	148	10	157	30	62	480
				2	49,954	96	192	5	96	390+	96	148	5	148	5	52	300
B. M.	13	80	56	2	14,281	96	180	5	90	480+	106	130	10	137	30	39	390
				1¾	42,293	90	180	5	90	390+	98	120	5	130	50	32	390

against a rise of 59 mm. after 45,511 foot pounds. The conclusion is justified that an increase in work is not necessarily accompanied by a proportionate increase in the blood pressure. The average rise amounted to 30 mm. for children from 6 to 9 years of age, from 35 to 41 mm. for the older children. The highest rise observed was 57 mm. in a boy aged 11; the minimum was 16 mm. in a boy aged 7.

Time of Maximum Reading of Blood Pressure.—Because of the recent work of Barringer[11] and Wilson, in which they claim that a secondary maximum rise of blood pressure sixty seconds or later after cessation of exercise indicates "temporary heart insufficiency," a thorough investigation into the time of the maximum reading after exhaustive exercise was made.

It is to be noted in Table 31 A that the majority of the subjects exhibit the maximum blood pressure at from five to thirty seconds. In general, 88 per cent. show the maximum blood pressure reading within thirty seconds after exercise. Twelve per cent. of the highest readings occur between thirty and sixty seconds. In only 1.1 per cent. is the reading highest at sixty seconds and later. Of the total number there were only four that could possibly be considered "delayed rises." One experiment in which the maximum reading was at sixty seconds (A. G., aged 12 years) was incomplete, only two readings having been obtained, one at thirty seconds and the other at sixty seconds. (M. S., aged 8) had a maximum reading at ninety seconds, the accuracy of which was doubtful. The two remaining subjects with a maximum rise definitely at sixty seconds were S. B., aged 11, and J. B., aged 8. The latter had the maximum reading at twenty seconds after having accomplished 18,300 foot pounds and a "delayed rise" after only 16,700 foot pounds. In neither instance did he show any subjective signs of "temporary heart insufficiency." The same is true of subject S. B. The results of this present investigation cannot be taken as a confirmation of Barringer's and Wilson's findings. Wilson tabulated sixty-five experiments with dumbbells. With the exception of four determinations the increase in blood pressure was proportionate to the increase in work. The time of the maximum reading also corresponded to the amount of work performed that is, the greater the quantity of work, the later the maximum reading. Readings at sixty seconds and after occured only after more severe exercise (from 2,000 to 3,000 foot pounds). Wilson found "delayed rises" in 21 per cent. of the experiments. It seems logical to assume that if she obtained

11. Barringer, T. B.: Studies of the Heart's Functional Capacity as Estimated by the Circulatory Reaction to Graduated Work, Arch. Int. Med. **17**:363 (March) 1916; **17**:670 (May) 1916. Studies of the Heart's Functional Capacity, Arch. Int. Med. **20**:329 (Sept.) 1917.

"delayed rises"—after her subjects performed about 2,000 foot pounds, that we should also have obtained similar results since our subjects performed from 50,000 to 60,000 foot pounds to the point of real exhaustion.

Reaction Time of Blood Pressure.—Wilson also claims that the reaction time of the systolic blood pressure is proportionate to the amount of work in almost all of her experiments. This is not in agreement with Tables 18 to 28. Comparison of the results obtained

TABLE 31.—A. TIME OF MAXIMUM READING AFTER EXHAUSTIVE EXERCISE

Sec.	Age									No. of Cases
	14 Yrs.	13 Yrs.	12 Yrs.	11 Yrs.	10 Yrs.	9 Yrs.	8 Yrs.	7 Yrs.	6 Yrs.	
5	3	4	5	3	7	7	2	4	2	37
10	7	6	10	3	1	3	4	6	4	44
20	7	7	6	6	2	4	10	3	1	48
30	3	1	5	2	6	3	5	5	1	31
40	1	2	2	0	2	2	1	2	0	12
50	1	1	3	3	..	..	..	..	..	8
60	1?	..	1?	1	..	..	1	..	..	2 and 2?
90	..	..	..	..	..	..	1?	..	..	1?
No. cases	22	21	31	18	18	19	23	20	8	
Aver.	18.4	19	18.2	24.6	19.1	16.5	18.2	18.5	15	

Average = 19; probable error = 3.33; coefficient variability = 0.26.

B. REACTION TIME OF BLOOD PRESSURE AFTER EXHAUSTIVE EXERCISE

Sec.	15 Yrs.	14 Yrs.	13 Yrs.	12 Yrs.	11 Yrs.	10 Yrs.	9 Yrs.	8 Yrs.	7 Yrs.	6 Yrs.	15-6 Yrs.
150	0	0	0	1	0	0	2	0	0	0	3
180	0	2	0	1	0	1	0	3	0	0	7
210	1	0	4	4	0	3	3	3	0	0	18
240	1	3	4	2	2	2	1	1	0	0	17
270	1	3	0	3	2	1	2	2	2	1	17
300	0	1	4	1	1	2	3	3	4	4	23
330	0	7	1	1	2	1	1	2	6	0	21
360	1	2	0	2	2	3	2	1	0	2	15
390	0	1	2	2	4	1	0	3	4	1	18
420	0	4	2	1	0	2	0	2	1	0	12
450	0	0	1	2	1	0	0	0	0	0	3
480	0	0	0	0	0	0	0	0	0	0	..
510	0	0	0	1	0	0	0	0	0	0	1
540	0	0	0	0	1	0	0	0	0	0	1
570	0	0	0	1	0	0	1	0	0	0	1
Delayed time	0	0	2	1	3	1	4	4	3	0	18

Average = 310; probable error = ±15.16; coefficient of variability = 7.25.

shows definitely that in 51 per cent. of the ergometer experiments the reaction time of the same subject is higher after larger amounts of work; that in 32 per cent. the reaction time is shorter though the work performed is higher (e. g. with subject B. M., aged 13, the reaction time is 390 seconds after 42,000 foot pounds and 480 seconds after 14,000 foot pounds.) In 14 per cent. of the experiments the reaction time is the same, though the subjects performed different amounts of work. I. C., aged 14, showed a reaction time of 180 seconds, though the work performed was 76,000 and 51,000 foot pounds, respectively.

In 3 per cent. of all readings the same amount of work in two repeated experiments was accompanied by different reaction times. The conclusion must be drawn that a direct ratio between the reaction time of the blood pressure and the increase of work is found in only a slight majority of subjects. The longest reaction time was 600 seconds in a boy, aged 13 (C. S.), and the shortest, 150 seconds (H. W., aged 9, J. B., aged 9, and A. M., aged 12). Statistical calculation shows the average to be 310.3 ± 15.16. The coefficient of variability equals 7.25. There is practically no change in reaction time with a change in age (Table 31 B).

Comparison of the Blood Pressure and Pulse Rate During and After Exercise.—Very few investigations of the physiology during exercise on adults have been made and none at all in children. In this work the readings were begun right after the onset of exercise and continued every minute throughout the entire experiment.

Pulse During Exercise (57 cases; Table 31).—The pulse showed an increase almost immediately after the beginning of the ride, remaining at a plateau for most of the period during exercise and usually descending toward the end of the ride. The pulses in six carefully studied cases showed that in one case the pulse rate immediately after cessation of exercise was twelve beats higher than during, in two the same and in the three remaining lower after than during exercise.

Blood Pressure During Exercise (Table 31; 75 cases).—The blood pressure showed a curve similar to the pulse rate except that its initial rise was slower. In eleven cases (26.6 per cent.) the blood pressure during exercise was on the average 10 mm. higher than after exercise. In forty-four cases (58.6 per cent.) it was the same and in twenty cases (26.6 per cent.) the systolic pressure during exercise was lower than the blood pressure immediately after.

CONCLUSIONS

1. Pulse rate and systolic blood pressure in normal children of school age: (1) The pulse rate in the standing posture is invariably higher than in the lying posture, the ratio being 1.15. (2) The systolic blood pressure in the lying posture is invariably higher than in the standing posture; the ratio of the pressure in the lying posture to that in the standing equals 1.11. (3) The ratio between the systolic blood pressure in the lying and the standing positions is about equal to the ratio between the pulse rate in the standing and lying positions.

2. Effect of exercise on the systolic blood pressure and on the pulse rate in normal children of school age: (1) All forms of exercise produce an increase in the pulse rate and the blood pressure, the increase depending mainly upon the type of exercise. (2) Neither

the amount of exercise nor the speed determine the time of maximum reading. (3) In the majority of cases the increase of the pulse rate and the blood pressure as well as the reaction time of the blood pressure are in direct proportion to the speed and the amount of work performed. (4) Height and weight do not influence the maximum physical output. (5) The maximum physical output is in direct relationship to the age, circumference of the chest, circumference of the thigh and the vital capacity. (6) Two formulas have been computed for calculating the maximum physical output with age as the basis. Formula I (applying to children from 6 to 10 years of age): 1,000 (5.45 age — 25.3). Formula II (applying to children from 11 to 14 years of age): 3,000 × age. (7) In exhaustive exercises on the ergometer, the increase of the pulse rate varies from 48 to 116 beats irrespective of age. It is not necessarily parallel with the amount of work performed. (8) In exhaustive exercise, the rise of blood pressure is proportional to the increase in work in about 50 per cent. of the experiments. (9) The average rise in blood pressure after exhaustive exercise equals 31 mm. in children aged from 6 to 9 years and 35 to 41 mm. in older children. The maximum rise equals 57 mm.; the minimum rise equals 16 mm. (10) Eighty-eight per cent. of all the determinations made show the maximum reading of the systolic blood pressure within thirty seconds, 12 per cent. between thirty and sixty seconds. In only two cases of the entire series is there a true delayed rise. In our experiments delayed rises do not occur after exhaustive exercise nor as the result of "temporary heart insufficiency." (11) The reaction time of the pulse is too long to be of any clinical value, very few pulse rates returning to normal within ten minutes. (12) In general, the reaction time of the systolic blood pressure increases with an increase in work. There are, however, exceptions to this conclusion. The average reaction time after exhaustive work equals 310 seconds, with a probable error of ± 15. The longest reaction time found is 600 seconds; the shortest is 150 seconds.

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CELIAC DISEASE*

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Samuel Gee described celiac disease in 1888. In 1921, Reginald Miller,[1] in compiling a retrospect of the literature concerning it, mentioned about fifty papers, but even his excellent bibliography is not complete. A study of this literature makes it evident that, in general, the accounts of celiac disease, celiac infantilism, Herter's infantilism, intestinal infantilism, acholia, pancreatic infantilism, pancreatic insufficiency and of a certain type of chronic intestinal indigestion agree fairly well in the description of a condition which we can hypothetically consider to be one specific morbid entity.

The disease has never been recognized in a breast fed infant. In its typical form it is always chronic. The children suffering with it are undersize and underweight. The roentgen ray shows delayed skeletal development and the muscles are small, soft and weak. This weakness is most noticeable in the legs. The abdomen is distended. The stools are voluminous, gray, greenish or brown, at times porridgy, at times containing much mucus and at times being liquid. They are usually foul, but may be rancid. Acute attacks of diarrhea occasionally occur; but for the major part of the time the patient has no more than two or three stools daily. These attacks of diarrhea usually occur after feeding carbohydrates or following the decomposition of retained bowel contents.

The fat content of the feces is greatly increased. This fat is usually fairly well split. The calcium outflow is likewise increased, and this increase over the normal is greater than is accounted for by the amount of fatty acid, volatile acid, or phosphate present in the stools.

The rate of metabolism is slightly diminished. There is usually some degree of secondary anemia and the spleen is often moderately enlarged. The mental ability of these children is usually far in advance of their physical powers. They are apt to be hypochondriacal. The most frequent complications are scurvy, tetany, edema and purpura.

The reports of fifteen necropsies are cited in the literature. At least ten of these must be thrown out of consideration, as there is no

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1. Miller: Brit. J. Child. Dis. **18**:11-17. (References included in Miller's Bibliography are not mentioned here.)

evidence that they were cases of celiac disease. Of the remaining five cases, three showed small celled infiltration and fibrosis, particularly about the pancreatic ducts, and one also showed fatty degeneration of the liver. I doubt whether more than one [2] of these represents the usual type of celiac disease. At any rate it is fully as probable that the lesions found followed long continued indigestion with its irritative bowel contents and abnormal bacterial flora as that they were causative of the disease. In the other two cases which are clearly typical of celiac disease, the necropsy showed no changes which could in any way account for the symptoms present. In particular it is to be noted that in neither of the two were pathologic changes found in the liver, duodenum or pancreas.

It has been suggested that the disease follows acute or subacute disorders of digestion and that it is at least associated with the abnormal presence of bacteria, such as *B. bifidus, B. infantilis,* and *B. coli* in the upper intestine. According to this view, the disease results from an infection either of the bowel contents or of the intestine, with a resultant defect in absorption. Other hypotheses as to etiology include chronic infection with one of the other type of dysentery bacillus; deficient or defective pancreatic secretion; deficient or defective secretion of bile; vitamin deficiency; and an overgrowth of proteolytic bacteria in the bowel contents which can be corrected by a change in diet.[3] Defective fat splitting seems to have played a prominent rôle in certain cases, but this was often temporary and, as a rule, the characteristic stools seem to have resulted not from indigestion per se, but from a defect in absorption which may be due to the same causes that produce the abnormal intestinal flora.

The present report is based on a study of seven cases, the cardinal features of which agree with those described as characteristic of celiac disease. Abstracts of their records and of the data gleaned from each appear as an appendix to this paper.

During the development and establishment of the disease, six of the seven patients received an unsuitable diet. In five cases the diet was largely cow's milk and carbohydrates, the principal form in which the latter was administered being potato. Eggs were given freely in three cases. One child subsisted for two years on Horlick's malted milk and bread and butter. Only one of the seven children was given a well balanced and variegated diet. In this instance, the disease developed after an attack of bronchopneumonia. In a second patient, the disease followed pertussis. Another child developed a condition

2. Porter: Am. J. Dis. Child. **6**:65 (July) 1913. Arroga and Vinas: Arch. de méd. d. enf. **3**:402.

3. Porter, Morris and Meyers: Am. J. Dis. Child. **18**:254 (Sept.) 1919.

similar to Banti's disease, and had all her digestive symptoms exaggerated following a hemorrhage from the bowel. A fourth child was, in spite of some indigestion, thriving fairly well; but developed all the symptoms of celiac disease immediately after an attack of chickenpox. Pertussis occurred six months after establishment of the disease in the fifth child, but apparently did not make the condition noticeably worse. In the sixth case there is no history of infection, and in the seventh case it is almost certain that there had been none.

In the light of these cases, it would seem that the best way to produce celiac disease is to feed a susceptible child throughout his second year on a diet rich in milk, fat, and potato, and then to subject him to some parenteral infection.

The roentgen ray, in each instance, showed a dilated atonic colon. The livers were uniformly small; in two cases the roentgen-ray shadow of the liver occupied only the area covered by two ribs and an interspace. The spleen was removed from one patient and showed hypertrophy of the connective tissue stroma, similar to that found in Banti's disease.

Free hydrochloric acid was absent in all of the five cases in which the stomach contents were examined. In two cases anacidity still persists in spite of marked improvement. In two others, including the one in which the spleen was removed, free hydrochloric acid is now present in the gastric juice. The test meal used consisted of toast and meat broth.

From three patients we obtained duodenal juice which contained bile salts, amylase, trypsin and bilirubin. In the only patient of the three whose symptoms were acute, it also contained large amounts of urobilinogen. As this patient was not anemic, and had received no toxic drugs, the presence of urobilinogen in the duodenal juice must mean diffuse liver pathology. It is of interest to note that Bahr encountered urobilinuria in several cases of sprue.[4]

In one case, which went on to exitus, leucin and tyrosin were found in the urine three months before death. This finding, likewise, indicates extensive disease of the liver.

Quantitative examinations of the fat in the stools of four of the patients were made by Dr. F. B. Kingsbury of the University of Minnesota. In the patient whose spleen was removed, the fat utilized before splenectomy was 72 per cent.; following splenectomy it had risen to 90 per cent. The per cent. of fat excreted unsplit before splenectomy was 36 per cent. and after splenectomy it was unchanged. In the patient whose duodenal juice contained urobilinogen, 72 per cent.

4. Bahr: A Report on Researches in Sprue in Ceylon, 1912-1914, quoted by Bauman: Arch. Int. Med. **28**:475 (Oct.) 1921.

of the excreted fat was split. In two cases 81 and 89 per cent. respectively, of the fat was utilized. In one case 11 per cent. of the excreted fat was unsplit, in the other 12 per cent.

In all cases it was found possible to alter the color and odor of the stool by changes in the diet.

Agglutination tests with the Flexner and Shiga types of dysentery bacillus were made in four cases, with negative results.

In support of the hypothesis that there is a causal relationship between the bad feeding and parenteral infection at the onset and disturbed gastric and hepatic functioning at the height of the disease are: (1) that the gastric juice of the infant aged 1 or 2 years normally contains less hydrochloric acid than does that of the adult; (2) that cow's milk has a much higher buffer value than breast milk;[5] (3) that parenteral infections often produce gastric anacidity; (4) that extensive but often unrecognized and usually transitory injury to the liver frequently occurs during bacteremias, and (5) [Whipple's[6] finding] that carbohydrate far more than protein or fats tends to protect the liver against toxic injury.

Marked carbohydrate intolerance had forced most of these patients to a protein and fat diet before they came under my care. At that time they were usually somewhat anemic; but their color was sallow as well as pale. Their livers were small, their intestines relaxed and distended and their stools foul, gray, fatty and voluminous. Up until one year ago the basis of our diet in these cases was protein milk to which other foods were gradually added. When acute exacerbations occurred we would resort to breast milk. For the past year we have begun treatment with a solution of Karo corn syrup flavored with orange juice. We have continued this for two or three days and have then gone over to Marriott's skimmed lactic acid milk to which we have added the curd of an equal quantity of skimmed milk.[7] With this we have been able, as a rule, to give 7 per cent. of Karo corn syrup. The initial improvement has been striking; the most noticeable feature being the striking change in the color of the skin, which has become pink and white instead of sallow. Coincidentally, the child's liver has become much larger. On this diet alone, two children, one aged 2 years and the other 4 years, have become able to walk. The first gained 13 pounds in nine months, the latter, 7 pounds in a year. The latter child grew 2 inches taller and began to walk before any addition was made to her diet. She was not receiving cod liver oil.

5. Marriott: Brit. J. Child. Dis. **18**:129-135.
6. Davis and Whipple: Arch. Int. Med. **22**:612 (Nov.) 1918.
7. Marriott: Proc. Washington University Med. Soc., October, 1921.

On protein milk the stools remained foul. On the lactic acid milk with added curd, they have not been foul. Formerly on the protein milk relapses were frequent. On the lactic acid milk they have occurred twice in one patient and not at all in two others who have come under treatment more recently and in whom greater care has been taken to prevent accumulation within the intestine. Furthermore, these patients tolerate more soluble carbohydrate with the skimmed lactic acid milk than they do with the protein milk.

To the lactic acid milk and curd we have slowly added such foods as scraped lean beef, gelatin, flourball porridge, toast, powdered spinach, emulsified cod liver oil, cream and egg yolk. Orange or lemon juice has been administered regularly in every case.

I have employed bile salts and dilute hydrochloric acid without producing any improvement but so far have had no experience in the use of pancreatic extracts nor secretin. In the three patients who were transfused because of anemia the procedure was followed by some digestive improvement.

In all cases we have found it necessary to give enough liquid petrolatum three times daily to secure regular bowel movements.

This discussion of treatment should not close without mention of the remarkable effect produced on the appearance of the stools by splenectomy in the patient who had developed Banti's disease. Three weeks after the operation they appeared altogether like normal stools. They were darker, firmer and contained much less fat than before, although the diet was precisely the same. In fact, the child became so constipated that a three day stool specimen could be obtained only by the use of enemas.

It appears that there are four points to be considered in successful dietary treatment: (1) In recognition of the achlorhydria, to use soured milk and fruit acids; (2) to supply readily absorbable carbohydrate primarily for its good effect on the liver; (3) to wait patiently for months on a high protein intake before adding starches and fats, and (4) to prevent fecal accumulations which can undergo bacterial decomposition.

SUMMARY

In all seven patients the disease was preceded by a long period of bad feeding, or by a parenteral infection, or by both.

Gastric achlorhydria was present in the five cases in which the stomach contents were examined.

The liver was found smaller than normal in every case. As further evidence of the presence of liver pathology there was in one case a complicating Banti's disease; in another case leucin and tyrosin were present in the urine, and in a third case the duodenal juice contained a pathologic pigment.

Finally, I wish to emphasize the remarkable therapeutic efficacy of lactic acid milk and corn syrup.

ABSTRACTS OF CASE RECORDS

CASE 1.—*History.*—P. H., boy, born January, 1917, was breast fed for about one year. After seven months he began to get cow's milk (from 1 to 1½ quarts daily), cereals, bread, potato and egg. When 16 months old he began to vomit occasionally and then was noticed to be getting thinner and weaker.

Examination.—At 18 months he was a flabby fairly well nourished boy with a distended abdomen. The stool was voluminous, foul, grayish and fatty.

Treatment.—This child was transfused; was fed on various diets, the most successful of which was breast milk, but he gradually failed and died at the age of 31 months.

Comment.—There was never much vomiting; but at times great anorexia. He showed the common complications of tetany and edema. His liver became very small and three months before his death the urine contained leucin and tyrosin. In this case there is no evidence of a parenteral infection; but the child had been grossly overfed, particularly with cow's milk. Attention is called to the very small liver and to the presence of leucin and tyrosin in the urine three months before death.

CASE 2.—*History.*—D. B., girl, born January, 1918, was breast fed ten months. She was well until August, 1919, when she had bronchopneumonia followed by a slow convalescence during which her abdomen was first noticed to be distended. In July, 1920, she had an acute diarrhea; since then she has had a continuous intestinal indigestion and has gradually lost strength.

Examination.—In October, 1921, the principal examination findings were: height, 35½ inches; weight, 26 pounds; small soft muscles; distended abdomen; liver edge palpable 1.5 cm. below the costal margin; spleen not palpable. The stools were voluminous, foul and fatty. Quantitative examination of the fat content of the stools showed that 35.5 per cent. of the weight of the dried feces was fat. Of this fat, 28 per cent. was in the form of neutral fat and 72 per cent. in the form of fatty acid and soaps.

Blood: Hemoglobin, 80 per cent.; red blood cells, 4,120,000; white blood cells, 9,850. Differential count: polymorphonuclears, 54 per cent.; lymphocytes, 43 per cent.; transitionals, 2 per cent.; eosinophils, 1 per cent.

Gastric Juice: Repeated examinations showed an absence of free hydrochloric acid. Duodenal juice was obtained from this patient at the height of her symptoms. It was green, ropy and slightly alkaline. It gave positive amylase and trypsin reactions. Lipase was not tested for. The Gmelin test was positive. The Pettenkoffer test for bile salts was positive. Urobilinogen was present in a dilution strength of 600 and urobilin in a dilution strength of 1,600. The urine contained no urobilin or urobilinogen. Dialysates of the blood plasma gave a negative reaction for bile salts. The agglutination test with the Shiga and Flexner types of dysentery bacillus was negative.

Comment.—Attention is called to the presence of urobilinogen in the duodenal juice. In the absence of increased blood destruction, this is proof of diffuse disease of the liver. This appears to be an instance of celiac disease developing after an acute parenteral infection.

CASE 3.—*History.*—A. O., girl, admitted September, 1921, aged 29 months, weight 20 pounds, height 29½ inches, was breast fed eight months. She was well until she had pertussis at 18 months. Then she began to have frequent vomiting attacks and soon after a diarrhea developed. At the time of the onset of this trouble the diet consisted largely of milk, eggs, potato, bread and butter. Vomiting continued practically up to the time of entrance to hospital (i. e., eleven months); diarrhea was present most of the time.

Examination.—The spleen was palpable but not so the liver. The stools were large, gray, fatty and foul. Oct. 24, 1921, there was no free hydrochloric acid and only a trace of total acid. Feb. 9, 1922, the free hydrochloric acid was 9, and the total acid 27.

Treatment.—This child showed great improvement on skimmed lactic acid milk and curd. As she improved, the liver edge came down below the costal margin. Her present height is 33 inches, weight 27 pounds.

April, 1922: Total fat intake in five days, 185 gm.; total weight of dried stool for five days, 65.6 gm.; total fat lost, 21.8 gm.; per cent. lost as neutral fat, 11; per cent. of fat utilized, 89.

Duodenal juice was green, ropy, slightly acid, but contained no urobilinogen. It contained urobilin in a strength of 1,000 dilutions. It gave positive amylase and trypsin reactions. The juice was rendered alkaline before ferment tests were made. It gave a positive Pettinkoffer test for bile salts.

Comment.—This is an instance of celiac disease developing after an attack of pertussis. Tests for liver function were not made during the height of the symptoms.

CASE 4.—*History.*—F. D., girl, born in 1913, was nursed until 15 months of age. When 1 year old, Horlick's malted milk was added to the breast milk. She was weaned from the breast at 15 months; then fed mainly on bread and butter and Horlick's malted milk. She did not like cow's milk. She failed to gain. The stools were foul and gray. In 1917 she stopped walking. In 1918 her height was 34 inches, weight 24 pounds. She had a severe secondary anemia; the spleen was moderately enlarged.

Treatment.—Two transfusions were given. The digestive condition gradually improved, with occasional remissions. When she was 6 years old her weight was 28 pounds; height, 36 inches. The spleen was 3 cm. below the costal margin. The liver was palpable.

Blood: The hemoglobin was 50 per cent.; red blood cells, 4,400,000; white blood cells, 5,600. Differential count: polymorphonuclears, 45 per cent.; small lymphocytes, 49 per cent.; large lymphocytes, 1 per cent.; transitionals, 5 per cent.

When she was 7 years old her weight was 31 pounds; height, 40 inches. The spleen was 3 cm. below the costal margin. The liver was palpable 2 cm. below the costal margin.

In 1921, at 8 years, she weighed 35 pounds. Her height was 40 inches. The spleen was 4 cm. below the costal margin. The urine contained no urobilin or urobilinogen. Gastric contents were totally anacid.

Blood: Hemoglobin, 70 per cent.; red blood cells, 4,400,000; white blood cells, 2,800; polymorphonuclears, 78 per cent.; lymphocytes, 22 per cent.

In January, 1922, profuse hemorrhage from the bowel was followed by a return of the indigestion. She was now 9 years old; weighed 36 pounds, and measured 42 inches in height. The spleen was 7 cm. below the costal margin. The liver was 1 cm. below the costal margin. Bile pigments were in the stool; of bilirubin there was a trace; urobilin and urobilinogen were present.

Blood: Hemoglobin, 40 per cent.; red blood cells, 2,900,000; white blood cells, 2,000; polymorphonuclears, 68 per cent.; small lymphocytes, 28 per cent.; large lymphocytes, 2 per cent., and eosinophils, 3 per cent.

There was a progressive diminution of leukocytes. The blood platelets numbered 440,000. The clotting time was seven minutes; the bleeding time, five minutes.

The total fat intake in five days was 120.45 gm.; the total weight of wet stools for five days was 234 gm.; the total weight of dried stools for five days was 52.2 gm.; the total fat lost in five days was 23.6 gm. Before splenectomy the neutral fat was 8.5 gm.; fatty acid and soaps, 15.1 gm.; per cent. of excreted fat split, 64; fat utilized, 72 per cent. of fat intake.

March 3, 1922, a large fibrous spleen, resembling the spleen of Banti's disease, was removed. The total fat intake in three days was 72.25 gm.; the total

weight of dried stools for three days was 24.7 gm.; the total fat lost in three days was 7.41 gm. Three weeks after splenectomy, the neutral fat was 2.52 gm.; fatty acid and soaps, 4.89 gm.; per cent. of excreted fat split, 64; fat utilized, 90 per cent.

Gastric contents: Free hydrochloric acid, 18; total acid, 60.

Comment.—This is an instance of celiac disease developing in a child on a malted milk and bread and butter diet. Later an affection resembling Banti's disease was made manifest.

Attention is called to the usual association between splenic disease of this character and liver disease, and, furthermore, to the probable infectious causation of Banti's disease.

CASE 5.—*History.*—M. E., girl, aged 3 years, entered in March, 1921, complaining of celiac disease. Her history states that she was fat and healthy when weaned at 7 months. She then went on a diet consisting mainly of cow's milk and potato. When 18 months of age she had pertussis; but her mother states that before this time her abdomen was distended and that she was passing voluminous foul stools.

Examination.—She was unable to walk; her abdomen was distended, her height was 32 inches and her weight 19 pounds. The stools were large, gray, foul and fatty. Urobilin was present. Repeated gastric analyses showed an absence of free hydrochloric acid. The liver when first examined was no wider than two ribs and an interspace. After one week's treatment the liver edge was palpable 2 cm. below the costal margin.

This child's present weight is 26 pounds and her height 34 inches. The gain of 2 inches in height has been made in the last two months. She is still on lactic acid milk and still has an achlorhydria. She is now running about and plays normally.

Comment.—This is a case of celiac disease apparently resulting from improper feeding, although pertussis may have played some part in its causation.

Attention is called to the extremely small size of the liver when the patient was first examined.

CASE 6.—*History.*—E. A., boy, born July, 1916, was breast fed for nine months. Then he was weaned, and thereafter for more than two years his diet consisted mainly of potato and cow's milk. During his second year he had frequent attacks of diarrhea and his abdomen became very much distended. During his third year, the indigestion gradually increased, and on two occasions he had general convulsions.

He came under my care at the age of 3¼ years. His weight was 23 pounds, height 32 inches. The abdomen was distended. Musculature was fairly good. The stool was voluminous, gray, foul, fatty and contained urobilin.

During the next eighteen months this child increased 7 pounds in weight and had become able to handle a fairly general diet. His abdomen was still distended and his stools still rather light colored and voluminous, but were not foul or noticeably fatty.

Comment.—This is an instance of celiac disease developing while the patient was being fed nearly altogether on milk and potatoes.

CASE 7.—*History.*—E. B., girl, was admitted June 7, 1921, aged 14 months; weight, 17 pounds. She had been breast fed seven weeks; thereafter was fed on cow's milk mixture. She had a diarrhea since she was 3 months old. At first the stools were greenish in color, but gradually they became whiter. In spite of her digestive disturbance, her general condition improved steadily, and when 11 months of age she was plump and beginning to walk. At this time she had chickenpox, and thereafter she stopped walking and became weaker and thinner.

Examination.—Her abdomen was distended; she had a secondary anemia; her spleen was palpable, and her stools were large, white and foul. She was transfused twice.

Treatment.—This child showed great improvement on skimmed lactic acid milk and curd. The gastric juice has been examined repeatedly and shows no free hydrochloric acid. She is now 32 inches tall, weighs 30 pounds and is beginning to walk. Her duodenal juice is green, ropy and slightly alkaline. It contains no urobilinogen. It contains urobilin in a strength of 600 dilutions. It gives positive tests to bilirubin, to bile salts, to trypsin and to amylase.

April 1, 1922: The total fat intake for five days was 185 gm.; the total weight of the dried stool for five days was 111 gm.; the total fat lost for five days was 37.7 gm.; per cent. of neutral fat, 12; per cent. of fat utilized, 81.

Comment.—This is an instance of celiac disease developing in an artificially fed young infant, the symptoms of which were exaggerated by an intercurrent parenteral infection.

Tests of liver function were not made at the height of disease.

THE TREATMENT OF FLAT WARTS BY THE INTERNAL ADMINISTRATION OF MERCURY *

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The suggestion of treating flat warts by the internal administration of mercury was first made by Dr. Charles J. White [1] in 1915. This method of treatment was tried on the supposition that warts were caused by some as yet undiscovered protozoon. In his first paper White reported seven cases and four additional cases were reported in a subsequent communication. All of the eleven cases, except one, showed a most favorable response at the end of a few weeks to the internal use of some form of mercury. Four of White's patients were adults, the ages of the others varying from 7 to 14 years. In addition to the internal medication, some of the patients were also treated locally by salicylic acid or other remedy.

The disease in question is often spoken of as verruca plana juvenilis, though it is by no means confined to juvenile patients. It generally appears on the face and hands, and in men is apt to affect the bearded region. The eruption consists of flat, pinhead sized, or larger, flesh colored, or slightly pinkish yellow, more or less polygonal papules. They may be discrete or aggregated (Fig. 1).

My personal experience in trying the method suggested by White is confined to eleven cases, one of which is not suitable for analysis as the patient was treated by another physician with the roentgen ray after she had taken mercury for one week. The result in this case was successful at the end of a few weeks. Of the ten cases in which the mercury treatment was given a fair trial the result was entirely successful in five. In these cases the disappearance of the eruption was absolutely complete in from three to eight weeks. There had, furthermore, been no return of the disease in these patients at the end of one, three, four and seven months and three years, respectively. The treatment consisted solely of the internal administration of mercurous iodid tablets in doses of ¼ grain, three times a day. Smaller doses were given the younger patients. No local remedies whatever were employed. In the five unsuccessful cases there was no improvement after two or four weeks of treatment.

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* Received for publication, Oct. 25, 1922.

1. White, C. J.: The Use of Mercury in Verrucae Planae Juveniles, J. Cutan. Dis. **33**:731 (Nov.) 1915; **34**:361 (May) 1916.

One of the most striking results was noted in the case of a young lady of 24 who had suffered for eight months from a profuse eruption of flat warts of the face and left hand. At the end of three weeks every lesion had completely disappeared without leaving a trace. Another patient who responded to treatment in a most satisfactory manner was a boy, aged 10 (Fig. 1), who had suffered for two months from an eruption of the face, forearms and left hand. He was given mercurous iodid tablets in doses of ¼ grain, three times a day. At the end of seventeen days the eruption had entirely disappeared from the face

Fig. 1.—Flat warts (verrucae planae juveniles) of two months' duration in a boy, aged 10 years.

leaving a few ill defined pigmented spots in place of the former lesions. On the hand the eruption had not quite disappeared. Mercury was continued for another week and was followed by the disappearance of the eruption on the hand. This patient was presented before the New York Dermatological Society on May 16, 1922.[2] In the discussion that followed Dr. Paul Bechet remarked that "the value of the mercurous iodid in the treatment of this condition had been demonstrated in a number of cases." He recalled a patient who recovered after a few

2. Arch. Dermat. & Syph. **6**:384 (Sept.) 1922.

weeks of treatment. Dr. Charles M. Williams stated that he had treated a number of cases by Dr. White's method and that "the first four patients made remarkable recoveries in from ten days to four weeks but the next patients did not improve at all." He added that "there was a class of warts for which mercurous iodid seemed to be effective, but it was impossible to tell beforehand what the result would be." Dr. H. H. Whitehouse remarked that "mercurous iodid was not effective in all cases and often failed." He had under observation a case "which improved to a certain degree but then stopped and new lesions were

Fig. 2.—Seventeen days after ingestion of mercurous iodid, ¼ grain, three times a day.

constantly appearing." Dr. Hans Schwartz reported two cases "which had cleared up entirely under treatment with mercurous iodid" and Dr. J. M. Winfield said that he had "treated a number of patients with mercurous iodid. It seemed to be a wonderful remedy in certain cases."

From my own limited experience and the remarks quoted there seems to be no doubt that in a certain proportion of cases of flat warts, successful results can be obtained by such a simple procedure as the administration of mercury by mouth for a few weeks. This method of treatment is comparable to the effects of radiation on common warts

(verruca vulgaris). At times the results of radium or roentgen-ray treatment are brilliant, at other times they are entirely unsuccessful. Flat warts can always be removed by the curet, a method, however, which is not an agreeable one, especially for the average child or

CASES OF FLAT WARTS TREATED BY INTERNAL ADMINISTRATION OF MERCURY

No.	Name	Sex	Age	Duration of Disease	Location of Disease	Duration of Treatment	Result
1	J. C.	F.	18	1 year	Face	1 month	Successful; no return at end of 1 month
2	M. B.	F.	24	8 months	Face and hands	3 weeks	Successful; no return at end of 3 years
3	D. N.	M.	46	Not recorded	Hands	3 weeks	Failure
4	N. W.	M.	36	18 months	Beard	3 weeks	Failure
5	D. A.	F.	16	3 years	Face and hands	3 weeks	Failure
6	I. S.	F.	27	4 years	Face and fingers	2 weeks	Failure; spontaneous disappearance 6 months later
7	F. G.	F.	23	1 year	Hand	4 weeks	Failure
8	S. W.	M.	10	2 months	Face, hands and forearms	4 weeks	Successful; no return at end of 7 months
9	E. G.	F.	3½	1 year	Face	3 weeks	Successful; no return at end of 4 months
10	B. K.	F.	5	1 year	Face	4 weeks	Successful; no return at end of 3 months

young woman. It is also well known that various types of warts may suddenly disappear spontaneously. As the mercury treatment is such a simple one, even though it often fails, it would seem rational to give it a trial before resorting to other less agreeable methods.

COMPARISON OF DIPHTHERIA IMMUNITY IN THE MOTHER AND IN THE NEW-BORN *

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The question of transference of antibodies, protein sensitization and infection, from mother to child has been studied much. Numerous investigators at various times have worked intensively on this subject.

The most easily proved transference of immune bodies occurs in the case of the well known immunity to diphtheria, which is present in a high percentage of new-born infants. This may be investigated either by examination of the cord blood serum, or by the intradermal toxin test (Schick test).

The most intensive studies on the diphtheria antitoxin content in mother and new-born that we have been able to find were made by von Groer and Kassowitz.[1] They made quantitative estimation on the antitoxin content of umbilical cord blood serum in 143 new-born infants, and compared these results with like estimation made on the blood serum of the mothers. They also did intradermal toxin injections in all of these patients, and also intradermal toxin-antitoxin injections in the mothers, first making comparison between antitoxin content of sera in mothers and new-born, and second between the cutaneous reactions. Of 143 mothers, twenty-three, or 16 per cent., showed no immune bodies in the serum, while 120, or 84 per cent., showed immune bodies present. Corresponding results were found in the offspring. The intradermal tests did not give similar results; ninety-one, or 63.6 per cent., of the mothers reacted positively, while only seven, or 4.9 per cent., of the babies gave positive reactions. In view of later work we do not feel that the markedly high percentage in the mother, and the small percentage in the babies can be accepted as it is now generally believed that from 15 to 20 per cent. of adults and infants give positive intradermal reactions; the most plausible explanation is that they were using too strong a toxin, although this leaves us at a loss to explain why so few positive reactions were obtained on the babies unless it was due to the technical difficulties of the intradermal injection in the new-born, which we shall mention later.

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* Received for publication Oct. 23, 1922.

* From the Nurseries of Maternity Hospital and the New-Born Clinic, St. Luke's Hospital.

1. von Groer and Kassowitz: Ueber das normale Diphtherie-antitoxin bei Mutter und Neugeboren, Ztschr. f. Immunitätsforsch. u. Exper. Therap. **23**:108 (May) 1914.

In 1917 Zingher [2] reported comparative results with the Schick test in mothers and infants up to the age of 24 months. The ages of the infants are not given exactly, but in three months groups. The series of infants up to the age of 3 months (twenty-three) is too small from which to draw conclusions. In eighteen instances, both mother and infant reacted negatively; in four instances both mother and infant reacted positively; in one case the mother gave a negative reaction, while the infant was positive, and in no instance did the mother react positively and the infant negatively.

In order to make further observations on the incidence of transference of diphtheria antitoxin from mother to child, we decided to make tests in 100 mothers and their new-born babies.

METHOD

Kind of Toxin.—The bulk toxin manufactured by the New York City Board of Health was used in all the tests. Fresh dilutions were made for each day's tests. In half the cases one-fortieth the minimum lethal dose was given in 0.2 c.c. and in the other half one-fiftieth the minimum lethal dose was given in 0.1 c.c. sterile saline. Intradermal injection was found much more difficult in the infants than in the mothers. Different sites on the arms and legs were tried without finding one more advantageous than another. The difficulty seemed to be due to the peculiar character of the infant skin. It was found that greater pressure is required to deliver the solution intradermally in an infant than in an adult. With the same technic the wheal is found to be considerably smaller in the infant and disappears much more quickly. Time determinations were made in ten infants and ten mothers; the averge time for disappearance of the wheal in the babies was three and a half minutes, while in the mothers it was twelve minutes. We are making histologic studies to determine, if possible, what factors are responsible for these differences. Some of the reactions mentioned below can probably be explained on the basis of the histologic structure of the skin in the new-born.

All the babies in this series were less than 7 days of age when tested. Most of the reactions were read at the end of two days and four days, and all were read at the end of a week. No control tests were made for pseudoreactions, but the repeated readings disclosed no pseudoreactions occurring in these very young infants. If the reaction was positive in twenty-four hours, it always persisted strongly positive at the final reading. In two babies the cutaneous reaction was

2. Zingher, A.: Further Studies with the Schick Test, Arch. Int. Med. **20**:392 (Sept.) 1917.

slight, but was accompanied by a deep infiltration in the skin and subcutaneous tissue, probably due to the rapid escape of toxin into the deeper tissues. A consistent difference in the intensity of the positive reaction was observed between mother and infant; the mother uniformly giving a more strongly positive reaction than her infant. Vesication was never seen in an infant, although it occurred in several of the mothers.

RESULTS

Ninety-five mothers and their babies gave corresponding reactions; twenty were positive and seventy-five were negative.

Four mothers gave positive reactions and their babies negative reactions; one of these babies was two months premature. If the

TABLE 1.—INTRADERMAL DIPHTHERIA TOXIN REACTIONS IN ONE HUNDRED MOTHERS AND NEW-BORNS

Mother and Baby Positive	Mother and Baby Negative	Mother Positive Baby Negative	Mother Negative Baby Positive
20	75	4	1

TABLE 2.—COMPARATIVE RESULTS OF INTRADERMAL DIPHTHERIA TOXIN REACTIONS IN MOTHERS AND NEW-BORNS

	Negative, Per Cent.	Positive, Per Cent.
Mothers	76	24
New-Born	79	21

transference of dihphtheria antibodies always occurs, as we believe, these negative reactions could best be explained, on imperfect technic, in the infants on account of the peculiarities of the skin, alluded to above. Negative reactions in the premature might be explained by the inability of the underdeveloped tissues to react to the toxin stimulus. We hope later to be able to publish a curve showing the relationship between the antitoxin content of serum and the fetal age.

In only a single instance was a positive reaction found in the baby with a negative reaction in its mother. This result we are not able to explain, unless the baby had absorbed from the mother more immune bodies than the mother had retained (Tables 1 and 2).

The close agreement in reaction between mother and baby seems to imply a direct transference of antitoxin immunity from mother to child. Eight of the babies giving negative reactions did not receive

breast milk or colostrum before the reactions were read. It is evident, therefore, that they received their immunity from the mother before birth. We concur with von Groer and Kassowitz that by the frequency of this phenomenon it must be considered a normal function of the placenta to transmit the antitoxin bodies from mother to child.

CHEMICAL STUDIES OF THE BLOOD OF MOTHER AND FETUS*

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The nutrition of the human fetus is a difficult subject to study on account of the almost complete isolation of this body. The physiologic activities of mother and offspring, as well as the rôle the placenta has played in the development of the latter, must be represented to a certain degree by the products of metabolism circulating in the blood streams of both organisms. By comparison of the amounts of nutriments and waste substances simultaneously present in the blood of each of the two subjects some information ought to be obtained concerning the "parasitic existence" of the fetus. Slemons [1] in particular has contributed some data to the question. However, the need for more positive evidence has led us to extend this type of work.

Do the derivatives of the protein and fat in the maternal intake reach the fetus in the form of "building stones" (such as amino-acids, etc.) or resynthesized products? Colloids have been shown not to traverse the placenta. Ascoli,[2] introducing egg albumin into pregnant animals subcutaneously or by the digestive tract, could detect it by the precipitin test in the material blood but not in the fetal blood. Mendel and Daniels [3] injected Sudan III into the circulation of pregnant rats; although the dye stained the maternal fat readily, it could not be found in the placenta or in the fetal body. More recently, Slemons and Stander,[4] studying the fat content of human maternal and fetal blood, found such a difference between the two that their results in conjunction with those of Mendel and Daniels led them to believe "that fat is not included among the materials contributed by the parent to her offspring.[5]" They likewise consistently found cholesterol and lecithin in greater amounts in the maternal blood than in the fetal blood. This observation is not in accord with a former study of Slemons and

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* From the Research Laboratories, Western Pennsylvania Hospital.

* The data in this paper are taken from an essay presented by Marion G. Howe to the Faculty of the Graduate School, Yale University, 1921, in partial fulfilment of the requirements for the degree of Master of Science.

1. Slemons, J. M.: The Nutrition of the Fetus, Yale University Press, 1919.
2. Ascoli, A.: Ztschr. f. Physiol. Chem. **36**:498, 1902.
3. Mendel, L. B., and Daniels, A. L.: J. Biol. Chem. **13**:71, 1912
4. Slemons, J. M., and Stander, H. J.: Cited by Slemons.[1]
5. Quoted from Slemons,[1] p. 39.

Curtis [6] in which they report identical quantities of cholesterol in the blood of mother and fetus.

Several investigators have indicated that there is a free exchange of crystalloids between mother and offspring. Sugar has been found by Morriss [7] to be present in greater quantity in the maternal than in the fetal blood but not in such quantities as to be unexplained by diffusion. Morse [8] reported a greater amount of amino-acids in the fetal blood. Although the difference is small, it is so constantly present that he concludes that the passage of amino-acids from mother to fetus cannot be explained by diffusion entirely. Stander and Tyler [9] reported what appear to them equal concentrations of ash in maternal and fetal plasma. There is likewise apparently free passage of waste products through the placenta. Slemons and Morriss [10] found such values of urea in both bloods that they considered them identical. Slemons and Bogart,[11] also Kingsbury and Sedgwick,[12] reported similar findings for uric acid; Plass,[13] and Hunter and Campbell [14] for the creatinin and creatin of the plasma.

As a result of the investigations, briefly reviewed, Slemons has concluded that the placenta acts like a semipermeable membrane through which the soluble substances pass by simple diffusion.

Experiments demonstrating the enzymatic action of placental tissue have led some to believe that this organ is actively engaged in preparing food in the proper form for the developing fetus; also, that it is endowed with power to yield excretory products. Hofbauer [15] demonstrated that glycerin extracts of the placenta contained glycolytic ferments; Hammett [16] showed that the quantity of urea increased in an aqueous suspension of placental tissue in the presence of a preservative; Cannata [17] noted that the placenta will break down uric acid. Contrary to the above results Morriss [7] has shown that the blood of twins, each with its own placenta, contained almost identical quantities of sugar (0.003 gm. difference per hundred cubic centimeters blood) and exactly identical quantities of nonprotein nitrogen. If the presence of either

6. Slemons, J. M., and Curtis: Am. J. Obst. **75**:569, 1917.
7. Morriss, W. H.: Bull. Johns Hopkins Hosp. **28**:140, 1917.
8. Morse, A.: Bull. Johns Hopkins Hosp. **28**:199, 1917.
9. Stander, H. J., and Tyler, M.: Surg., Gynec. & Obst. **31**:276, 1920.
10. Slemons, J. M., and Morriss, W. H.: Bull. Johns Hopkins Hosp. **27**: 343, 1916.
11. Slemons, J. M., and Bogart, L. J.: J. Biol. Chem. **32**:63, 1917.
12. Kingsbury, F. B., and Sedgwick, J. P.: J. Biol. Chem. **31**:261, 1917.
13. Plass, E. D.: Bull. Johns Hopkins Hosp. **28**:137, 297, 1917.
14. Hunter, A., and Campbell, W. R.: J. Biol. Chem. **34**:5, 1918.
15. Hofbauer: Cited by Morriss.[7]
16. Hammett, F. S.: J. Biol. Chem. **37**:105, 1919.
17. Cannata, S.: Fol. clin., **2**:34, 1911.

of these substances, the nonprotein nitrogen representing several nitrogenous constituents, depended on the enzymatic action of the placentas in this case of twins, one would hardly expect such precise quantitative correspondence.

EXPERIMENTAL

The subjects for study were patients at full term in the department of obstetrics of the Western Pennsylvania Hospital, Pittsburgh. In virtually all of the cases an anesthetic was administered—generally nitrous oxid and oxygen analgesia during part of the first and all of the second stage, the labor being ended under complete anesthesia by combining ether with the nitrous oxid. In a few of the cases the sole anesthetic was ether given only at the end of the second stage. A few of the patients were delivered by forceps, under ether anesthesia.

The blood of the fetus, taken from the placental end of the cord as soon as it was cut, was allowed to flow into a small sterile bottle containing sufficient potassium oxalate (usually 25 mg.) to prevent clotting. Coincidently, as nearly as possible, blood was taken from a vein in the mother's arm.

The methods of analysis were those of Folin and Wu [18] on tungstic acid filtrates involving the improved procedure [19] for sugar determination.

Although creatinin determinations were made on twelve sets of maternal and fetal bloods, the colorimetric readings were so unsatisfactory that the results have not been tabulated despite the fact that the averaged data agreed closely.

Virtually equal concentrations of creatinin have been found in maternal and fetal plasmas by other investigators. Hunter and Campbell [20] report that in whole blood some substance is freed, by the Folin technic, from the corpuscles which contributes to the color and is variable. Plass,[18] independently, came to the same conclusions. By two different methods he could find no regular relationship between the whole bloods but values for the plasmas agreed closely.

The results for nonprotein and urea nitrogen are recorded in Table 1. The nonprotein nitrogen content of the mother's blood is not the same as that of her offspring in every case; a similar discrepancy appears in the case of urea. However, if the average value for each of these constituents in maternal and fetal blood is calculated, one is confronted with almost identical figures. The average nonprotein nitrogen for mothers' blood is 23.8 per hundred cubic centi-

18. Folin, O., and Wu, O.: J. Biol. Chem. **38**:81, 1919.
19. Folin, O., and Wu, O.: J. Biol. Chem. **41**:367, 1920.
20. Hunter, A., and Campbell, W. R.: J. Biol. Chem. **32**:195, 1917.

meters; for fetal blood it is 23.8 per hundred cubic centimeters of blood; the average urea nitrogen for mothers' blood is 11.8 per hundred cubic centimeters; for fetal blood it is 10.9 per hundred cubic centimeters blood. Despite the identity of these averages, marked differences in individual cases may still exist and be of significance. The differences given by Slemons [1] are also tabulated in Table 2. He does not

TABLE 1.—NONPROTEIN NITROGEN AND UREA NITROGEN; MG. PER 100 C.C. OF BLOOD

No.*	Para	Source	N. P. N.	Difference in Favor of		Urea N.	Difference in Favor of		Remarks
				M †	F †		M	F	
5	I	M	....	...	...	13.2	1.5	...	Nitrous oxid, whiffs of ether
		F	....	...	...	11.7			
6	I	M	28.0	...	1.1	17.2	1.4	...	1′ 48″ nitrous oxid
		F	29.1	...	...	15.8			
9	I	M	24.6	0.5	...	13.6	2.6	...	Ether
		F	24.1	...	...	11.0			
11	I	M	23.8	0	0	11.4	1.8	...	2′ nitrous oxid,
		F	23.8	...	...	9.6			
14	I	M	21.3	0	0	10.5	...	0.1	1′ 57″ nitrous oxid
		F	21.3	...	...	10.6			
16	I	M	22.2	4.2	...	10.8	0.6	...	15″ ether; syphilis
		F	18.0	...	...	10.2			
3	II	M	....	...	...	9.7	1.1	...	No anesthesia
		F	....	...	...	8.6			
4	II	M	....	...	...	9.7	0.4	...	No anesthesia
		F	....	...	...	9.3			
7	II	M	27.6	...	2.1	13.1	0.1	...	2′ 18″ nitrous oxid
		F	29.7	...	...	13.0			
10	II	M	26.1	0.6	...	10.9	0.4	...	Nitrous oxid, ethyl-chlorid and ether
		F	25.5	...	...	10.5			
15	II	M	21.7	...	2.6	13.9	1.9	...	30″ nitrous oxid
		F	24.3	...	...	12.0			
13	III	M	21.5	...	0.6	11.0	0.9	...	Whiffs of ether
		F	22.1	...	...	10.1			
8	IV	M	22.1	1.8	...	9.5	0.2	...	Nitrous oxid
		F	20.3	...	...	9.3			
17	IV	M	....	...	...	11.7	0	0	Whiffs of ether
		F	....	...	...	11.7			

* The case numbers in Tables 1, 4 and 6 are the same. There was a small clot in the fetal blood in Cases 2, 4, 5, 10, 12 and 16. The clots were too small to make an appreciable difference. Furthermore, the distribution of the constituents in plasma and corpuscles is such that a clot would not alter analytical results.

† M denotes mother; F, fetus.

consider the variations significant but concludes that the concentration of nonprotein nitrogen and urea is equal in maternal and fetal bloods. We hesitate to disregard entirely these differences in the case of urea especially. All the bloods were obtained within a few seconds to a very few minutes of each other, and where the greatest variation occurred, 4.2 mg., the time of collection of the two bloods was identical.

Table 2 has been constructed on the assumption that 0.5 mg. or more is an actual difference, that is, beyond the range of technical variation. The nonprotein nitrogen represents urea, amino-acids, creatinin, uric acid and rest nitrogen. Why does not the greater amount of amino-acids in the fetal blood, evidence for which has been given previously, cause a corresponding difference in the nonprotein nitrogen? In 57 per cent. of our cases the urea was higher in the maternal blood, the average increase being 1.5 mg. per hundred cubic centimeters of blood. The concentrations of creatinin are practically equal. In the case of uric acid, it will be noted presently that there is apparently a slight retention in the fetus. May not the greater quantity of urea nitrogen in the mother's blood counterbalance the excess of amino-acid nitrogen in the fetal blood? If such is the case, it helps to explain why there is not a regular preponderance of nonprotein nitrogen in favor of the fetus.

TABLE 2.—SLEMONS' DIFFERENCES

Mg. N. P. N. in Favor of		Mg. Urea N in Favor of	
Mother	Fetus	Mother	Fetus
...	0.3	0.4	...
...	0.7	...	0.9
1.7	...	0.9	...
1.0	...	...	1.9
0.5	...	0	0
3.5	...	1.4	...
0	0	0.9	...
...	1.3	...	1.4
1.7	...	1.4	...
0.3	...	0.5	...
0	0	...	0.9
...	1.0	...	0.9
...	0.5	...	0.4
5.5	...	0.5	...
3.0	...	1.4	...
...	0.2	0.9	...

Whether this difference in urea content is of any significance and of what it is significant we are not prepared to say. The well known fact that animal tissues, in general, are very permeable to urea makes one pause to consider any difference in concentration of this substance in two solutions separated by a membrane. The average difference—1.5 mg. of urea nitrogen—is equivalent to 3.2 mg. of urea. Therefore, in 57 per cent. of the cases studied the mother has 3.2 mg. more of urea in each 100 c.c. of whole blood than the fetus. One possible explanation in this connection is that the maternal kidneys do not remove the urea quite as rapidly as it is brought to them. The fetus is in need of a great deal of nitrogenous material, especially near the end of gestation, and the waste therefrom must be removed. Another suggested explanation is that the membrane may be impaired by various factors incident to delivery so that at parturition equal concentra-

tions cannot be maintained. It is also conceivable that the number of cells undergoing metabolism is much greater in the mother than in the fetus. Neither anesthesia nor surgical intervention affect apparently either the nonprotein nitrogen or the urea. Of course, a final answer to this phase of the subject cannot be given until analyses of blood are secured in cases involving the two possible interfering factors. Finally, instead of being due to a temporary derangement of the membrane, the difference may be due to individual imperfections that have kept such a variation between maternal and fetal blood quite constant throughout pregnancy. In considering the 57 per cent. of cases in which there was an excess of urea in the maternal blood, it must not be forgotten that 43 per cent. of the cases were identical. The small variation has been discussed at some length because not only does it seem especially significant in the case of urea, but it raises the question whether a slight quantitative difference in other constituents of the blood of mother and fetus is really significant.

TABLE 3.—COMPARATIVE TABLE CONSTRUCTED FROM TABLES 1 AND 2

	Number of Cases	Identical, per Cent.	In Favor of		Average Difference	
			Mother, per Cent.	Fetus, per Cent.	Mother, Mg.	Fetus, Mg.
N. P. N.						
Authors	10	20	40	40	1.8	1.6
Slemons	16	31	44	25	2.5	0.9
Urea N:						
Authors	14	43	57	..	1.5	...
Slemons	16	19	50	31	0.98	1.20

Does uric acid "enter the maternal circulation as freely as if the placenta did not exist?" From data summarized in the last two columns of Table 5 Slemons,[1] and Kingsbury and Sedgwick [12] have answered this question in the affirmative. Slemons' values are from normal patients. Kingsbury and Sedgwick make no statement in regard to this point, but presumably, judging from their values, the data are normal.

The third column summarizes results of Slemons' studies in which there are involved such complications as nephritis, preeclamptic toxemia, induction, deep chloroform, and premature twins. The complications are of such different type that it is doubtful whether anything is gained by grouping them. At least there is little cause to believe that the relationships as brought out by the table are altered in any characteristic way by such heterogenous factors. The resemblance to our results is striking. They can be interpreted in no other way than that there tends to be some retention of uric acid in the fetus. The conditions of birth may account for the large excess in Case 15. Delivery was

delayed on account of uterine inertia. The fetal heart sounds, taken often, were slow, and the fetus, when delivered, was blue. Before definite conslusions can be drawn in regard to a tendency for a greater amount of uric acid in the fetal blood than in the maternal a careful study of more cases is essential.

TABLE 4.—URIC ACID; MILLIGRAMS PER HUNDRED CUBIC CENTIMETERS OF BLOOD

No.	Para	Source	Uric Acid	Difference in Favor of		Interference	Anesthetic Used *	Duration of Labor, Hours
				M	F			
5	I	M F	4.3 5.1	...	0.8	.....	Nitrous oxid, whiffs of ether	19
6	I	M F	4.7 5.0	...	0.3	Low forceps	1′ 48″ nitrous oxid	14½
9	I	M F	4.0 3.7	0.3	...	Mid forceps	Ether	29½
11	I	M F	6.9 6.9	0	0	Mid forceps	2′ nitrous oxid; ether	9
14	I	M F	4.2 4.2	0	0	.....	1′ 47″ nitrous oxid	14½
16	II	M F	3.5 4.5	...	1.0	Low forceps	15″ ether (syphilis)	9¾
3	II	M F	1.0 0.9	0.1	...	.....	.....	14
7	II	M F	5.1 5.3	...	0.2	Mid forceps	2′ 18″ nitrous oxid	14
12	II	M F	4.9 4.9	0	0	.....	50″ nitrous oxid, whiffs of ether	12
15	II	M F	3.8 5.2	...	1.4	.....	30″ nitrous oxid	7
13	III	M F	4.4 3.8	0.6	...	.....	Whiffs of ether	38
8	IV	M F	2.9 3.7	...	0.8	.....	Nitrous oxid	5½
17	IV	M F	3.2 3.4	...	0.2	.....	Whiffs of ether	18

* In the instances where nitrous oxid was used during labor, its administration was for analgesia not anesthesia.

It would seem that either the placenta is a barrier to uric acid or diffusion lags behind accumulation. Almost immediately after birth the fetus urinates so that the fetal kidneys have begun to function some time before parturition. Before birth, then, the transition period has set in when there are two pairs of kidneys operating on each side of the placenta. That this early renal excretion is not very efficient has been shown by Kingsbury and Sedgwick.[12] They found that the blood of new-borns contain more uric acid the first three or four days of life than either maternal or placental blood. It is not out of place to recall here the oft described occurrence of uric acid infarcts in the kidneys of the new-born coming to necropsy. Viewed in

this light it is not strange that uric acid, the first substance to be retained by impaired kidneys,[21] should tend to accumulate on the fetal side.

The actual amount of uric acid present exceeds in the majority of cases the upper normal limit. In order to ascertain whether such high values are characteristic of pregnancy the blood of pregnant patients, otherwise normal, was examined. The results are given in Table 6. The values are quite within the normal range, from 1 to 3.5 mg. uric acid per hundred cubic centimeters blood. Slemons has noticed a similar increase in uric acid in the blood of mother and fetus at parturition and explains it as possibly being due to a temporary renal insufficiency quite characteristic of labor. It has already been noted that uric acid is the first of the waste products to be retained in disorders of the kidney. This fact makes it quite possible to have a retention of uric acid and no retention of urea (Table 1). We are inclined to believe that the uric acid content is higher in primiparas. There is

TABLE 5.—COMPARATIVE TABLE CONSTRUCTED FROM TABLE 4 AND DATA OF SLEMONS AND OF KINGSBURY AND SEDGWICK

	Number of Cases	Identical, per Cent.	In Favor of		Average Difference	
			Mother, per Cent.	Fetus, per Cent.	Mother, Mg.	Fetus, Mg.
Authors	13	23	23	54	0.33	0.67
Slemons, complications involved	15	7	33	60	0.7	0.95
Slemons	12	17	41.5	41.5	0.64	0.3
Kingsbury and Sedgwick	14	7	43	50	0.37	0.27

no value in Table 4 below 3.5 mg.; the highest is 6.9 mg. No doubt, a harder labor is associated with a greater renal disturbance. Not only a decreased urinary output but possibly an increased formation accounts for the high uric acid. It will be noticed in Table 4 that several of the higher values accompany prolonged anesthesia. With no anesthesia, the value is only 1 mg. per hundred cubic centimeters of blood. Mann [22] has demonstrated that etherization of dogs causes leukocytosis and it is known that an increase of white cells increases the blood uric acid. This experiment is cited as possibly throwing some light on the relationship between the anesthesia and the amount of uric acid.

The results for sugar are recorded in Table 7. The average value for mothers' blood was 0.125 per cent.; for fetal blood it was 0.103 per cent.; the difference being 0.022 per cent. These results agree closely with those of Morriss,[5] making them mutually confirmatory. By the Lewis and Benedict method his mean value for mothers' blood was 0.132 per cent.; for fetal blood 0.115 per cent., and the difference 0.017 per cent.

21. Myers, V. G.: Practical Chemical Analysis of Blood, 1921.
22. Mann, F. C.: J. A. M. A. **57**:172, 1916.

That the values recorded for mothers' blood are due to a temporary increase is beyond question. In Table 8 the blood sugar values for women at different periods of pregnancy are given, typical values and all within the range of perfectly normal figures. The average is 0.088 per cent. as against 0.125 per cent., the average of a group of parturient women. The change from a normal blood sugar to what may constitute a condition of hyperglycemia is a rapid one. In Case 5, two hours before delivery the blood sugar was 111 mg. per one hundred cubic centimeters of blood. At delivery it had increased by 48 mg. In Case 3, in which the blood was examined at the very beginning of labor, there was an increase of 31 mg. Our data are substantiated and extended by those of others. Analyses by Schiller [23] show no hyperglycemia during the later months of pregnancy or the first two weeks after. Morriss [7] concludes from his intensive studies that the

TABLE 6.—URIC ACID DURING PREGNANCY; MILLIGRAMS PER HUNDRED CUBIC CENTIMETERS BLOOD

Number	Para	Period, Months	Uric Acid
1	1	2-3	2.5
2	XI	3	3.5
3	V	6	2.7
4	II	6	1.9
5	III	6	3.2
6	IV	8	3.0
7	II	8	3.3
8	I	8½	2.5
9	V	9	1.6
10	II	9	2.8

blood sugar is increased during the second stage of labor, being normal during pregnancy and the puerperium.

This relatively high blood sugar content at the end of the second stage of labor is due to one or both of two causes, namely: muscular work and anesthesia including analgesia. In Case 3, one of these factors is ruled out, there being no anesthetic employed. The patient's age (the first pregnancy occurred seventeen years previously) could account for a hard labor. The increase of 31 mg. of sugar per hundred cubic centimeters of blood must be due to the contractions of the uterus and probably to voluntary efforts of the mother. Even during menstrual uterine contractions the blood sugar has been shown to increase slightly.[24] It is not strange, then, that there is a marked increase when this organ is convulsed with the heaviest waves of contraction of which it is capable. In regard to the voluntary muscular efforts of the mother, one cannot claim certainly that they are a contributing factor for it has not been shown that the blood sugar always increased after such muscular

23. Schiller, H.: Surg., Gynec. & Obst. **39**:450, 1919.
24. Kahler, H.: Wien. klin. Wchnschr. **27**:417, 1914.

activity. Experimental results are not uniform. Though the response is evidently somewhat variable, there is a rise in most cases.

How much of the high blood sugar is due to an adaptation of the organism to feed the working muscles and how much is due to ether or nitrous oxid it is impossible to say. The effect of the anesthetic alone can never be studied in normal confinements or those approximating normal, because muscular contractions are always present. But

TABLE 7.—Study of Sugar in Blood; Grams Per Hundred Cubic Centimeters Blood

No.	Para	Age	Source	Sugar	Difference in Favor of M	Interference	Anesthesia	Duration of Labor, Hours
5	I	23	M *	0.111				
			M	0.159	0.022	.....	Nitrous oxid, whiffs of ether	19
			F	0.137				
6	I	29	M	0.160	0.022	Low forceps	1′ 48″ nitrous oxid	14½
			F	0.138				
9	I	22	M	0.127	0.127	Mid forceps	Ether	29½
			F	0.100				
11	I	30	M	0.103	0.011	Mid forceps	2′ nitrous oxid; ether	9
			F	0.092				
14	I	22	M	0.137	0.048	.....	1′ 47″ nitrous oxid	14½
			F	0.089				
16	I	19	M	0.088	0.004	Low forceps	15″ ether	9¾
			F	0.084				
3	II	37	M †	0.122				
			M	4.153	0.024	.....	.....	14
			F	0.129				
7	II	24	M	0.098	0.009	Mid forceps	2′ 18″ nitrous oxid	14
			F	0.089				
10	II	28	M	0.147	0.027	.....	Nitrous oxid, ethyl-chlorid ether	12
			F	0.120				
12	II	23	M	0.112	0.023	.....	50″ nitrous oxid, whiffs of ether	5
			F	0.089				
15	II	..	M	0.112	0.015	.....	30″ nitrous oxid	7
			F	0.097				
13	III	34	M	0.108	0.026	.....	Whiffs of ether	38
			F	0.082				
8	IV	30	M	0.122	0.025	.....	Nitrous oxid	5½
			F	0.097				

* Two hours before labor. † Before labor.

several experiments can be cited to show that nitrous oxid, ether and chloroform increase blood sugar. Epstein and Aschnor [25] reporting on fourteen gynecologic operations with nitrous oxid and ether anesthesia showed an increase of 32 per cent. of sugar after the operation. They believe with the exception of nephrectomy that the anesthetic is the important factor and not the operation itself. Obstetric operations were performed in five of the thirteen cases recorded in Table 7, but

25. Epstein, A. A., and Aschnor, P. W.: J. Biol. Chem. **25**:151, 1916.

there is nothing distinctive in regard to the maternal blood sugar, except that two of them, Cases 16 and 7, are among the lowest. It is very apparent that the interference cannot account for an increase. Rouzaud [26] reports a hyperglycemia under general chloroform anesthesia and Hirsh [27] the same results with both ether and chloroform. Contrary, then, to the response of the organism to voluntary muscular work, the response to an anesthetic is a regular one, depending on an actual disturbance of the sugar metabolism.

It seems quite probable that a psychic factor may account for some of the increase in blood sugar. Referring again to the work of Epstein and Aschnor [25] no apparent relationship between pain or great fear of the operation and the concentration of sugar could be detected. On the other hand, a neurotic patient of Morriss [7] developed hyperglycemia as the result of a great disturbance over having a sample of blood taken from her arm.

TABLE 8.—Sugar During Pregnancy; Grams Per Hundred Cubic Centimeters Blood

Number	Para	Period, Months	Sugar
1	I	2-3	0.088
2	IV	6	0.082
3	V	6	0.086
4	II	6	0.128
5	IV	8	0.058
6	II	8	0.093
7	I	8	0.085
8	I	8½	0.080
9	I	8½	0.085
10	I	9	0.064
11	II	9	0.125

Age, duration of labor, and number of pregnancies seem to influence the amount of the increase but they are so interwoven that it is difficult to make any definite statements. The average for the six primiparas, even with the comparatively low value in Case 16, is higher than the average of any of the other groups.

Mild hyperglycemia in the mother's blood, brought about by muscular contractions, the anesthetic, and possibly pain and deep emotions has been considered. What of that in the fetal blood? The excess in favor of the mother and the close agreement of the average amount in excess with that found by Morriss has already been noted. This difference is probably due to the fact that sugar is being produced in the mother more rapidly than it can diffuse through the placenta and establish equilibrium. An increase of 32 mg. per hundred cubic centimeters of blood in two hours gives some idea of the rate at which sugar is being poured into the maternal circulation. Where there is

26. Rouzaud: Compt. rend. soc. biol. **82**:727, 1919.
27. Hirsh, E.: Z. Physiol. Chem. **93**:355, 1915.

no apparent great increase in the maternal blood, that and the fetal blood are more nearly of equal concentration, as for example, in Cases 11, 16 and 7. Slemons [1] believes the excess sugar in the mother's blood to be an arrangement "on the basis of diffusion" [28] to insure a steady supply for the fetus. An "arrangement" and diffusion are hardly compatible. It would seem that rather than be a special adaptation, the unequal concentrations are the result of physical laws. The sugar in the mother's blood rises very rapidly and diffuses through the placenta but the rate of diffusion cannot keep up with the production.

The distribution between mother and fetus of some of the products that have been considered does not necessitate a complex mechanism to account for the passage of fetal food and waste products through the placenta. They have been found in such amounts as to be most reasonably explained by dialysis which appears to operate in spite of the fact that the pressure in the maternal blood stream is much greater than that in the fetal blood. For this reason, if for no other, the process is hardly a "simple" one. Whether one is justified in interpreting equal concentrations as a result of diffusion, and markedly unequal concentrations as an absence of diffusion, may be disputed. Cholesterol is not normally found in the spinal fluid or only in extremely small concentration, but in certain pathologic conditions it is found in varying amounts, depending on the change that the membranes have undergone.[29] In these cases the meninges becomes partially permeable. A corollary can be drawn in regard to the placenta. There is a possibility of its being partially permeable to some substances. The evidence as far as fats are concerned seems to indicate that no degree of diffusion takes place.[3] Still another possibility is that enzymes can account for both equal and unequal concentrations, but the basis for such an adaptation remains largely speculative. Diffusion affords a more rational explanation.[30]

SUMMARY

Normal values for the content of nonprotein nitrogen and urea nitrogen in maternal blood prevail at parturition.

The concentration of nonprotein nitrogen in maternal and fetal blood is not the same in every case but there is no consistent preponderance in either blood. Inasmuch as the value for nonprotein nitrogen represents the sum of several nitrogenous constituents, it alone

28. Quoted from Slemons **1**:36.

29. Levinson, A.; Landenberger, L. L., and Howell, K. M.: Am. J. M. Sc. **151**:561, 1921.

30. We are greatly indebted to Dr. Paul Titus for his cooperation in allowing us to take samples of blood from his patients.

cannot be considered as indicating a free interchange of these constituents through the placenta.

In 43 per cent. of the cases studied, the concentration of urea nitrogen in the two bloods was identical. In 57 per cent. of the cases there was an average of 1.5 mg. more urea nitrogen in 100 c.c. of maternal blood than in the same volume of fetal. This excess may be explained by maternal renal insufficiency or impairment of the placenta. It is not obvious whether such a difference is physiologically significant.

The concentration of blood uric acid of parturient women tends to be higher than normal. In 54 per cent. of the cases studied there is an average difference between maternal and fetal blood of 0.67 mg. per hundred cubic centimeters blood in favor of the fetus. The retention may be explained by fetal renal insufficiency.

The concentration of blood sugar is temporarily increased at parturition owing to the anesthetic, muscular contractions and possibly a psychic factor. The maternal values are consistently greater than the fetal. The average difference between the two values in the cases studied is 22 mg. per hundred cubic centimeters blood. We believe this difference is due to the fact that the rate of production is greater than the rate of diffusion.

Diffusion offers the most reasonable explanation for the passage of nutrients and waste products through the placenta.

THE COLLOIDAL GOLD REACTION IN ACUTE POLIOMYELITIS *

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The reactions obtained with the colloidal gold test in syphilitic diseases of the central nervous system and the various forms of meningitis are fairly well established and have proved of value in diagnosis. Several investigators have reported their results with the reaction in cases of acute epidemic poliomyelitis, most of the studies having been carried out during the 1916 epidemic. These papers have been quoted at length in a previous publication [1] and will not again be referred to here.

One of us (J. C. R.) previously reported [1] a series of twenty-one cases including seventy-four spinal fluids examined at intervals varying from the fourth to the one hundred and twenty-third day of the disease. The results obtained in this previous series and in the present one have been fairly uniform. Any differences will be called attention to in the accompanying text.

From June to November, 1921, forty-nine cases of acute poliomyelitis were received at the Kingston Avenue Hospital. Eight patients died, a mortality of 16.3 per cent. The ages of the patients varied from 1 year or less to 21 years. The types of the disease were: Myelitic, 38.8 per cent.; bulbopontine, 14.3 per cent.; polyneuritic, 2 per cent.; Landry's paralysis, 2 per cent.; myelitic and polyneuritic, 24.5 per cent.; myelitic and bulbar, 18.3 per cent.

In forty-two of these forty-nine patients a study of the cerebrospinal fluid by means of the colloidal gold test was made, a total of 132 spinal fluids being thus examined. These fluids were removed at intervals ranging from the fourth to the eighty-fourth day of illness, 107 fluids being obtained in the first six weeks.

Divided according to the respective weeks in which they were taken, the fluids were distributed as follows:

First week	14 fluids	Seventh week	11 fluids
Second week	21 fluids	Eighth week	6 fluids
Third week	16 fluids	Ninth week	3 fluids
Fourth week	21 fluids	Tenth week	2 fluids
Fifth week	21 fluids	Eleventh week	2 fluids
Sixth week	14 fluids	Twelfth week	1 fluid

* Received for publication, Oct. 23, 1922.

* From the Kingston Avenue Hospital, of the Bureau of Hospitals, Department of Health, New York City; Dr. R. J. Wilson, director, and Dr. William T. Cannon, resident physician.

1. Regan, J. C., and Cheney, G. W. H.: Amer. J. Dis. Child. **23**:107 (Feb.) 1922.

The following results were obtained:

1. *Zone in Which the Poliomyelitic Reduction Occurs.*—In no instance was a normal reaction encountered in any poliomyelitic fluid taken during the first few weeks, or in what is to be considered as the very acute period of the disease. The type of reduction found was constantly in the same zone, the zone of low dilutions, the so-called syphilitic zone. A characteristic type of reduction in the first week or two is 11½22100000. In ninety-one of the 132 spinal fluids the reaction was limited to the first five dilutions (from 1:10 to 1:160) and fell strictly within this zone. In twenty-six of the remaining fluids it extended into the sixth dilution (1:320) and in twenty-two of these twenty-six instances the reading was either 0½ or 1, and hence practically negligible. In thirteen of the remaining fourteen fluids the reaction reached the seventh dilution (1:640) and in one fluid the eighth dilution. In other words, in more than 68 per cent. of the spinal fluids, the reduction of colloidal gold was limited to dilutions of from 1:10 to 1:160, and in 88 per cent. to dilutions of from 1:10 to 1:320.

In ten cases of the forty-two, the reaction extended beyond the sixth dilution, but commonly this extension occurred during the earlier period of the disease, and in all instances except two it was limited to a 0½ or 1 reduction. The type of the disease in such patients has commonly presented certain characteristics, that is, the polyneuritis was marked, or occasionally meningitic symptoms were pronounced, or extensive paralysis existed. It would seem, in general, then, that in acute poliomyelitis the colloidal gold chlorid reaction is rather sharply limited to dilutions of from 1:10 to 1:320, with the exception of certain patients who presented marked polyneuritis or meningitic symptoms.

2. *Variations of the Height of the Reaction at Various Periods of the Disease.*—By summarizing the total number of curves in the various weeks and taking a mean average, it was found that the average curve is highest in the first and second weeks, and then gradually declines reaching an almost normal level by the eighth week.

It is to be noted that the average curve for the respective weeks was slightly lower in the present series than in the previous series.

3. *Description of the Average Reactions in the Various Weeks.*—In the first week the reduction encountered in this series started in the red blue in 1:10 extended into the lilac or purple in from 1:40 to 1:80, and descended somewhat more abruptly into the reddish blue color in 1:160, reaching the nonreducing red again in 1:320. In the second week, the curve was very similar; in the third week, there was a slight lowering in the height of the curve. In the fourth week, there was a

decided change and the reaction fell entirely in the red blue from 1 : 10 to 1 : 160. In the sixth week, the red blue was reached only in from 1 : 40 to 1 : 80, and finally in the eighth week the average reaction was entirely confined to the normal nonreducing red color. Figure 1, curves *a, b, c, d,* show the type of average curve obtained in the first, third, fifth and seventh weeks, respectively.

4. *Time of Disappearance of the Positive Reaction in the Different Cases.*—One patient showed a normal reaction as early as the third week; four patients had a normal reaction in the fourth week, three in the fifth week, three in the sixth week, two in the seventh week, and two in the eighth week. Thus of the spinal fluids of twenty-three patients examined up to or beyond the eighth week, fifteen, or 65 per cent., presented a normal reaction by this time. In this connection, it

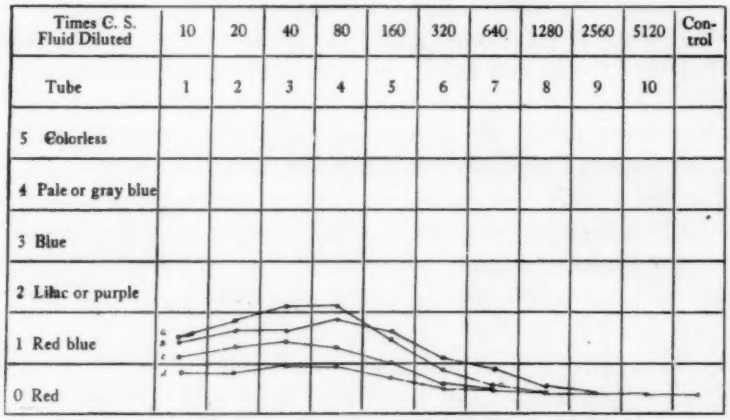

Fig. 1.—Average curves for the first (a), third (b), fifth (c), and seventh weeks (d) of the disease.

is to be noted that only 30 per cent. of the cases in the first series showed a normal reaction by the eighth week.

Of the eight patients with a positive reaction reaching to the eighth week or beyond, the last puncture was performed in the eighth or ninth week and found still positive in five cases, and negative in one case, while of the remaining two cases one became negative in the eleventh week, and the other still persisted positive when the last fluid was taken in the eleventh and twelfth weeks, respectively.

Hence, it seems that in poliomyelitis the colloidal gold test rarely reaches normal before the end of the third week, and that in one half of the cases it continues elevated still at the end of the eighth week, persisting when all other pathologic changes in the spinal fluid have commonly disappeared.

5. *The Relation of the Type of the Disease to the Subsidence or Persistence of the Positive Colloidal Gold Reaction.*—(*a*) These cases with an early subsidence of the positive reaction from the third to the seventh week, were characteristically mild types of poliomyelitis in which polyneuritis, if any had been present at all on admission, rapidly disappeared, the paralysis quickly improved, or vanished, and the child became convalescent early and made an excellent recovery. (*b*) It was commonly the more severe cases with extensive and slowly improving paralysis and with moderate or marked neuritis in whom the curve remained elevated to the eighth week and beyond.

6. *Reactions in Fatal Cases.*—The type of reduction in the spinal fluids of four fatal cases examined was very much like that found in the nonfatal cases in the first week of the disease.

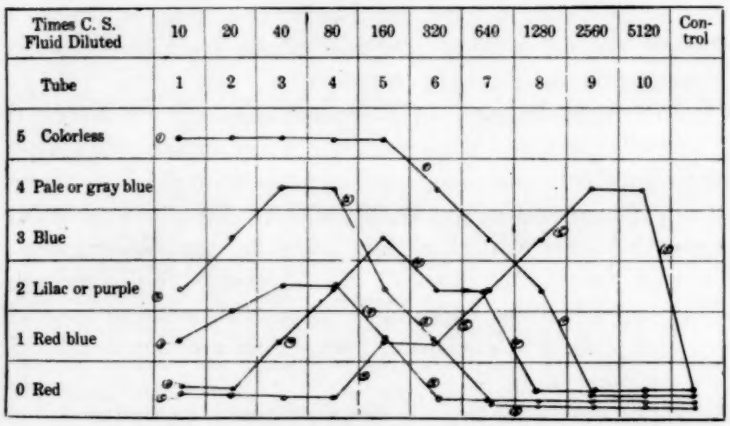

Fig. 2.—Comparative curves in various diseases: (1) General paresis, 5 5 5 5 5 4 3 2 0 0; (2) cerebrospinal syphilis, 2 3 4 4 2 1 0 0 0 0; (3) acute poliomyelitis, 1 1½ 2 2 1 0 0 0 0 0; (4) tuberculous meningitis, 0 0 1 2 3 2 2 0 0 0; (5) epidemic cerebrospinal meningitis, 0 0 0 0 1 1 2 3 4 4.

7. *Relationship Between the Cytology and Chemistry of the Spinal Fluid and the Colloidal Gold Reaction.*—(*a*) The amount of globulin has borne no relationship to the height of the colloidal gold curve. Often a high curve would be accompanied by a low or absent globulin reduction, or vice versa, a high globulin reduction would be found with a low curve. The presence or absence of globulin in the spinal fluid has borne no definite relationship to the positive or negative gold chlorid reaction.

(*b*) There was no definite relation between the height of the gold chlorid curve and the number of cells per cubic milimeter in the spinal fluid. However, as the weeks of the disease passed, and the cell count decreased, the gold chlorid reaction subsided, but this latter was much

slower in its decline, and in the majority of cases remained elevated for a period of several weeks after the cell count had reached normal levels, which occurred in this series between the second and third weeks.

8. *Value of the Reaction in the Diagnosis of Poliomyelitis.*—Certain diseases have a reaction in the same zone as poliomyelitis. These diseases may be divided into several groups: (1) Various forms of syphilis of the nervous system—tabes dorsalis, syphilitic meningitis, gumma of the brain, etc. (2) Various forms of insanity—dementia praecox, senile psychosis, paranoia, maniac depressive insanity, imbecility, alcoholic psychoses, etc. (3) Acute encephalitis due to various infectious causes, and brain abscess. (4) Postdiphtheritic paralysis. These first four groups give quite constantly reactions in dilutions of from 1:10 to 1:160 or 1:320 and similar grades of precipitation as seen in poliomyelitis. (5) Then there is a fifth group including diseases which occasionally are said to give reactions in this zone—epilepsy, spinal cord tumor, chorea, multiple sclerosis, edema from sunstroke, tuberculous meningitis and epidemic encephalitis.

The differential diagnosis of poliomyelitis from these diverse conditions cannot be discussed here in detail. A few salient points, however, will be pointed out. The differentiation of poliomyelitis from syphilitic diseases of the nervous system should offer no difficulties. The history, symptoms and other laboratory data, including the Wassermann reaction, will be sufficient to establish the diagnosis. It is very essential in the case of all poliomyelitic fluids tested with colloidal gold also to make a spinal fluid Wassermann test. This precaution was carried out in the present series.

The various forms of insanity certainly cannot be confused clinically with poliomyelitis. It is only the encephalitic form of poliomyelitis which would likely be confused with an acute encephalitis and this form is relatively rare.

Postdiphtheritic paralysis is commonly readily recognized by the history of a previous angina, by the more gradual afebrile, or practically afebrile, onset, the localization of the paralysis in certain characteristic muscles (soft palate, extrinsic or intrinsic muscles of the eye, etc.), and the absence of a meningeal syndrome of onset. The lack of any increase of cells in the spinal fluid, and the rapid improvement with eventually complete disparition of the paralysis without atrophy will almost always settle a question of differential diagnosis.

Epilepsy, spinal cord tumors, chorea, and multiple sclerosis are clinically not to be confused with poliomyelitis, unless under exceptional circumstances.

Tuberculous meningitis in its early stages gives, at times, a reaction in the lower dilutions resembling, then, somewhat a poliomyelitic reduc-

PARTIAL BRIEF SUMMARY OF CASES WITH SPINAL FLUID EXAMINATIONS *

Case No.	Date of Onset	Age	Cerebrospinal Fluid Examinations				Paralysis on	
			Date Taken	Globulin	Cells per C.Mm.	Colloidal Gold Reactions	Admission	Discharge
1849	9/18	15 mo.	9/24	0	17	1 1½2 2 1 0 0 0 0 0	Bulbar and right lower	Died
1909	10/ 3	5 yr.	10/10	0	80	1 1 1 1½1 1 0 0 0 0	Bulbar	Died
1742	8/26	4 yr.	8/30	0	10	1 1½2 2 1½0 0 0 0 0	Bulbar	Died
1951	10/13	20 mo.	10/22	1+	35	1 1½2½2 1 ½0 0 0 0	Left lower	Weakness left foot
			11/ 7	0	12	0 0 0 0 0 0 0 0 0 0		
2031	10/27	4 yr.	11/ 9	0	10	1 1 1 1½1½0 0 0 0 0	Neck, back and weakness lower extremities	None
			11/17	0	5	1 2 1 1 1 0 0 0 0 0		
			12/17	0	0	0 0 0 0 0 0 0 0 0 0		
1999	10/27	4 yr.	11/ 1	0	120	½1 1 ½ ½ ½0 0 0 0	Neck, left facial, tongue	Slight left facial
			12/ 2	0	0	0 0 0 0 0 0 0 0 0 0		
1786	8/26	2 yr.	9/27	1+	112	3 2½ ½2 2½1 0 0 0 0	Neck, back and lower extremities	Partial, both lower
			9/30	0	50	1 1½2 1 0 0 0 0 0 0		
1589	7/ 9	8 yr.	7/21	1+	24	1 1 1 2 3 3 3 0 0 0	Back, left arm and both lower	Partial, both lower
			7/24	1+	60	1 2 2 3 3 3 3 2 0 0		
			9/15	?	?	0 0 0 0 0 0 0 0 0 0		
1764	8/31	2½ yr.	9/ 8	0	5	1 1 2 1½1 ½0 0 0 0	Neck, back and both lower extremities	Complete left lower and weak right lower
			10/24	0	0	1 1 1 ½0 0 0 0 0 0		
1780	9/ 1	17 mo.	9/ 9	0	10	2 2 1½1 1 ½0 0 0 0	Right lower	Partial right lower
1663	7/14	3 yr.	8/12	1+	0	½ ½1 2 0 0 0 0 0 0	Back, right upper and right lower	Slight weakness right lower
			8/26	0	0	0 0 0 0 0 0 0 0 0 0		
1819	9/10	2 yr.	10/ 4	0	37	1 1 2 1 1½0 0 0 0 0	Right lower	Partial right lower
			10/23	0	5	1 1 1 1½1 0 0 0 0 0		
1824	9/16	2 yr.	10/ 3	0	42	½1 1½2 2 1½1½0 0 0	Back, neck, both upper and both lower extremities	Both upper and lower extremities
			10/11	0	180	1 2½2 1 ½0 0 0 0 0		
			10/13	0	20	1 1 1 2 2½0 0 0 0 0		
			10/27	0	5	1 1 2 0 0 0 0 0 0 0		
1802	9/10	15 mo.	10/ 4	0	135	1 1½2 2 2 1 0 0 0 0	Right lower and partial right upper	Partial right lower
			10/13	0	15	1 2½1½ ½ ½ ½0 0 0 0		
			10/23	0	7	1 1½1 ½0 0 0 0 0 0		
1885	9/28	3½ yr.	10/ 5	0	65	½1 2 2 ½0 0 0 0 0	Soft palate and slight deglutit.	Slight palatine
			10/13	0	0	1 ½ ½ ½0 0 0 0 0 0		
1861	9/20	2 yr.	10/ 4	0	15	1 2 1½1 ½0 0 0 0 0	Partial both lower extremities	Weakness both lower extremities
			10/13	0	17	0 0 0 0 0 0 0 0 0 0		
			10/23	0	2	0 0 0 0 0 0 0 0 0 0		
1615	7/12	3 yr.	8/16	1+	4	1 2½2 2 ½0 0 0 0 0	Partial both upper and lower extremities	Partial right upper
			8/25	1+	0	½1 1 2 1 0 0 0 0 0		
			9/ 6	0	5	0 0 0 0 0 0 0 0 0 0		
1897	10/ 2	11 yr.	10/12	1+	12	1 1 2 3 2 ½0 0 0 0	Back, left lower and partial right lower	Weakness right lower and partial left lower
			10/20	1+	10	1 1 1½1½2 2 0 0 0 0		
			10/26	1+	15	½1 1½ ½ ½0 0 0 0 0		
			11/15	1+	0	0 0 0 0 0 0 0 0 0 0		
1947	10/16	3 yr.	10/20	0	40	1½2 2 2 1½1 1 0 0 0	Right lower extremity	Weakness right lower
			10/28	0	32	½1½2 1½0 0 0 0 0 0		
			11/ 3	0	2	1 1 1 ½ ½0 0 0 0 0		
			11/ 9	0	5	0 0 0 0 0 0 0 0 0 0		
1820	9/10	10 mo.	10/ 6	0	85	2½1 2 ½ ½0 0 0 0 0	Neck, back partial both lower	Partial left lower
			10/13	0	12	1 1 2 2 1 0 0 0 0 0		
			10/20	0	0	1 1 1 1 0 0 0 0 0 0		
1911	10/ 5	1 yr.	10/12	0	45	2 3 2½1 ½0 0 0 0 0	Left lower extremity, left upper extremity	Partial left lower and upper
			10/27	2+	12	1 1 1½2 0 0 0 0 0 0		
			10/31	0	5	½ ½ ½1 ½ ½0 0 0 0		
			11/ 7	0	0	0 0 0 0 0 0 0 0 0 0		
1724	8/15	16 mo.	12/ 1	0	6	1 1 2 2 1½ ½0 0 0 0	Neck, back, diaphragm, right upper, bases of lungs	Partial right upper
			12/15	0	7	1 1 1 1½0 0 0 0 0 0		
			12/28	0	0	½1 1 1 1 0 0 0 0 0		
			12/30	0	0	0 0 0 0 0 0 0 0 0 0		
2010	10/24	9 yr.	11/ 1	2+	15	1 1 1 2 2 2 0 0 0 0	Both lower and partial back	Partial right lower and weakness left lower
			11/29	1+	1	1 1 2 3 2 2 0 0 0 0		
			12/24	0	0	0 ½ ½1 2 0 0 0 0 0		

* Owing to lack of space only a partial summary of the cases with spinal fluid findings could be included.

tion. But as the disease develops, the curve is prolonged out into the meningitic zone. In the early stages there are also the history, symptoms and the other spinal fluid findings, including cell increase, globulin and sugar reductions. The cell increase is apt to be greater, the globulin higher, and the sugar reduction less in tuberculous meningitis. Moreover, tubercle bacilli may be found.

Epidemic encephalitis, according to the small number of reports made on the subject, gives a colloidal gold reaction of a variable type.[2] In a considerable number of cases it is said to be negative, while in others a reaction of a paretic, meningitic or syphilitic type is encountered. Accordingly, it may be said that while a syphilitic type of reaction may occur in epidemic encephalitis and in poliomyelitis, a negative, a paretic or meningitic type of curve is encountered only in the former. Obviously, the clinical picture of the two diseases is quite distinctive, and there are a great many clinical points on which a differential diagnosis is usually readily based. The same may be said of any acute encephalitis and also of brain abscess. Another point is, that the cytologic and, at times, chemical reactions are more commonly absent in this condition than in poliomyelitis.

Meningismus due to various diverse causes—gastro enteritis, pneumonia, acute infections, etc., is seldom accompanied, in our limited experience, by a spinal fluid which produces marked reduction of colloidal gold. If any reaction occurs it is usually so slight as to be negligible.

The importance of the colloidal gold reaction in epidemic poliomyelitis, may be overlooked if it is forgotten that other positive findings in the augmentation of cells and globulin may be very slight, slightly beyond normal, and may be entirely absent after the first several days of the disease have passed. It is in such instances that the constancy of a syphilitic type of curve is especially of assistance in diagnosis.

SUMMARY

In a series of forty-two cases of acute poliomyelitis, including 132 spinal fluids, a study of the colloidal gold reaction was carried out. The spinal fluids were obtained at various intervals from the fourth to the eighty-fourth day of the disease.

CONCLUSION

The following conclusions were drawn from the results obtained in this and a previous series of cases.

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2. Tilney, F., and Howe, H. L.: Epidemic Encephalitis, New York, Paul Hoeber, 1920, p. 105.

1. There was always a reaction with colloidal gold solution in the case of every poliomyelitic fluid taken during the acute stage of the disease.

2. This reduction was constantly in the same zone—the zone of low dilutions, the so-called syphilitic zone. In 88 per cent. of the spinal fluids examined, the reaction occurred in the first six dilutions between 1 : 10 to 1 : 320.

3. In fourteen spinal fluids the reaction extended to the seventh dilution (1 : 640). These patients more or less characteristically presented marked polyneuritic or meningitic symptoms, or else pronounced paralysis.

4. The average curve or reaction showed very similar characteristics in the first and second weeks of the disease. A gradual decline in the curve was then observed.

5. In no instance was a normal reaction encountered before the end of the third week of illness.

6. In twenty-three patients the spinal fluid was examined as late as the eighth week, and fifteen, or 65 per cent., had become normal by that time.

7. Cases in which a normal reduction returned early, from the third to the seventh week, were mild types of the disease, while those in which the curve remained elevated beyond the eighth week had usually polyneuritis or extensive and slowly improving paralysis or both.

8. The reaction showed no distinctive points in the fatal cases, and, therefore, was of no value in prognosis in this regard.

9. The positive reaction bore no constant relation to the presence of globulin in the spinal fluid, nor to its disappearance.

10. There was no close ratio between the number of cells per cubic millimeters in the spinal fluid and the test, but as the cell count decreased, the colloidal gold curve subsided, somewhat more slowly, however, remaining elevated for several weeks after the cell count was normal.

11. With the subsidence of the colloidal gold reaction there is usually concomitantly an accompanying improvement in the patient's general condition, the paralysis, the meningitic symptoms and the polyneuritis. In fact, it would seem that the return of a normal reduction of colloidal gold indicates approximately the end of the acute stage of the disease. As this coincides with the improvement observed clinically, this termination of the acute stage can readily be determined by watching the symptoms. The colloidal gold reaction is naturally not to be used as a routine to determine this.

12. In differential diagnosis the colloidal gold reaction should be utilized in conjunction with the history, symptoms and other laboratory

data, and thus employed it is one of the most valuable tests we have for the recognition of the disease. While its significance is possibly not quite as great, it is far more constant and persistent than either the cell or globulin increase. Its possible use in the preparalytic stage of the disease must not be forgotten.

We wish to acknowledge the excellent assistance given by Miss Helen Meyers, of the laboratory staff, in the performance of the laboratory portion of the work.